DEVELOPMENT OF EQUATIONS TO DETERMINE THE INCREASE IN PAVEMENT CONDITION DUE TO TREATMENT AND THE RATE OF DECREASE IN CONDITION AFTER TREATMENT FOR A LOCAL AGENCY PAVEMENT NETWORK

A Thesis

by

MAITHILEE MUKUND DESHMUKH

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Roger Smith
Committee Members,	Stuart Anderson
	Thomas Wehrly
Head of Department,	David V. Rosowsky

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ABSTRACT

Development of Equations to Determine the Increase in Pavement Condition due to Treatment and the Rate of Decrease in Condition After Treatment for a Local Agency Pavement Network. (May 2009)

Maithilee Mukund Deshmukh, B.E., Sardar Patel College of Engineering, Mumbai

Chair of Advisory Committee: Dr. Roger Smith

Cost effective maintenance of pavement sections requires timely preventive maintenance and planned rehabilitation treatments. Knowledge of the increase in condition due to application of treatment and the loss of condition after treatment are essential when deciding the maintenance and rehabilitation treatments. Any error in formulating these values can cause significant changes in recommendations provided. Many researchers have developed pavement performance prediction models; however, less research has been done on the impact of treatment actions on the condition of a pavement section after treatments. The objective of the research is to develop equations, using deterministic empirical method, that predict the increase in pavement condition and rate of decrease in pavement condition after treatment actions with respect to pavement condition just before the treatment. The equations are developed for different treatments and different functional class, and surface type combination to quantify the impact of the treatment for the use in pavement management system. These equations can be used to quantify the effects of different treatments for the use in pavement management system.

Numerical illustration is presented using the data from the Metropolitan Transportation Commission-Pavement Management System software developed by the Metropolitan Transportation Commission (MTC) located in Oakland, California. A relation is observed between increase in pavement condition and pavement condition just before treatment for different treatments and different functional class and surface type combination. Hence the equations to determine the trend in increase in pavement condition for different treatments and different functional class and surface type combination are developed. For rate of decrease in pavement condition, due to large variability in the data the loss of pavement condition per year could not be related to pavement condition just before treatment. Hence the equations to determine the trend in loss in pavement condition after treatment could not be developed. The developed equations can be efficiently used to predict increase in pavement condition due to application of the treatment and the loss of pavement condition after treatment.

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CHAPTER I

INTRODUCTION

The total miles of road in USA are about 4,000,000; about 2,500,000 miles of roads are paved roads. Flexible pavements represent a major part of total paved roads in USA accounting for approximately 90 percent of the paved roads [1]. The condition of pavements deteriorates over time with utilization and ageing. To maintain their functionality, periodic maintenance and rehabilitation actions are required. These activities require large amounts of resources, and agencies, such as departments of transportation, spend large amounts of resources every year just to maintain the conditions of the existing pavements to provide the desired service level [2].

Preventive maintenance treatments are applied periodically to the pavements in good condition to reduce the rate of deterioration, whereas rehabilitation treatments are generally applied to improve the condition of the pavements [3]. If the periodic preventive maintenance treatments are not carried out, the pavement deteriorates to an extent where the rehabilitation treatment needs to be provided which requires higher cost. If the treatments are not applied to the pavement, it goes on deteriorating until it reaches the threshold value below which the pavement cannot function as desired. Hence,, maintenance and rehabilitation treatments are necessary to keep the pavement condition above the desired service level.

Maintenance treatments are divided into preventive maintenance and corrective maintenance. Preventive maintenance is applied when pavements are in good condition and slow down the pavement deterioration but do not necessarily improve the structural

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This thesis follows the style of the journal of Reliability Engineering and System Safety.

capacity of pavements. On the other hand corrective maintenance, as the name suggests, is used to repair deficiencies and is generally applied when the roads are significantly deteriorated [3]. Preventive actions generally include planned strategies of treatments such as slurry seal, cape seal, crack seal, chip seal, micro surfacing, etc. A slurry seal treatment is a surface application used to maintain, protect and prolong the life of an existing asphalt pavement. It is normally applied when the pavement is in good condition. It is cold mixed asphalt and consists of a graded aggregate, an emulsified asphalt binder, fines, and additives. Chip seal is constructed by evenly distributing a thin base of hot bitumen or emulsified asphalt on an existing pavement and then embedding a single sized aggregate into it. Chip seal is typically used on rural roads carrying lower traffic volumes. It keeps the pavement in good condition by sealing out water, but provides no structural strength. Chip seal is used to repair minor cracks and is known as an effective low cost way to maintain roads. Cape seal type of treatments is the application of a chip seal followed within a few weeks by a slurry seal. Cape seal is applied when the pavement deterioration is such that applying only a slurry seal would not be effective. Cape seal lasts longer than slurry seal and chip seal and is used to treat cracks. It is smoother than a chip seal and more durable than a slurry seal. Crack seal type of treatment is used to seal cracks and is the least expensive type of preventive maintenance treatment. Emulsion based cold crack sealant or hot crack sealant can be used to seal cracks [4].

Rehabilitation actions are more expensive and extensive corrective actions to repair the pavements which have deteriorated to a level at which the preventive actions should not be applied. Rehabilitation treatments generally include structural overlays, reconstruction, recycling, etc. and are generally applied to improve the functional and/or structural capacity of pavements [4].

Since the maintenance and rehabilitation actions require large amounts of resources to provide reasonable service levels, these activities need to be planned in an optimal manner. Complex decisions need to be made about how and when to apply the treatments to keep the highway performing, and operating costs at a reasonable level [5]. For some small pavement networks, the maintenance and rehabilitation decisions like type of treatment to be applied, funds required, etc. are made based on engineering knowledge and experience of the managers. With growing pavement networks and diminishing available funds, the selection of sections for treatment that provide the best return on invested funds is generally assisted by a pavement management system (PMS) [5].

A structured pavement management system includes a computerized decision support system that helps evaluate the pavement maintenance and rehabilitation strategies based on the forecasted values of the pavement attributes, subject to predetermined criteria, and constraints. A PMS in general is used to help manage a pavement network and to provide information supporting overall asset management. The data in a PMS is generally stored in the form of a database which includes the inventory data, inspection or performance data, parametric data for performance equations, and unit cost for different treatments. Various analysis tools like performance prediction models that are required to analyze a pavement also form an important part of the PMS [5].

Performance prediction models are used in PMS to predict the value of various attributes like condition, damage, and structural performance to assist in decision making. They also help in predicting the performance of the pavement with and without the potential maintenance and rehabilitation treatments to compare the change in condition of the pavement when a treatment is applied to the condition when the treatment is not applied. This information is then used to identify appropriate maintenance and rehabilitation strategies that satisfy performance constraints, and the agency's budget. Some researchers have developed performance prediction models that predict the condition of the pavement, and helps to identify when the treatment is needed [6, 7, 8]; however, it is difficult to find literature on the impact of the treatment actions on the condition of pavement sections after the treatments. The objective of this research is to develop the equations that predict the increase in pavement condition, and rate of decrease in pavement condition after treatment actions, to quantify the effects of different treatments for the use in a local agency PMS.

1.1 Problem Statement

When a treatment is applied, the pavement condition is improved. The increase in the pavement condition depends on the type of treatment applied. The amount of this increase in pavement condition with a particular type of treatment with respect to the condition of pavement just before the treatment is needed to quantify the impact of that treatment for use in a PMS. Likewise, the rate of condition decrease following a treatment application is needed to show the long term impact of the treatment on the pavement. Errors in these values can cause significant changes in recommendations provided. These equations in addition to the performance equations can be used in a PMS to evaluate the impacts of maintenance and rehabilitation strategies.

1.2 Objectives

The objective of the proposed research is to develop the following prediction equations for the use in a PMS used by local agencies in the San Francisco, California, Bay Area:

1) Develop the pavement condition index increase equations to predict the increase in the pavement condition after the treatment for different functional class and surface type combinations for different types of maintenance treatments.
2) Develop the pavement condition index loss equations to predict the loss in the pavement condition per year for different treatments for different functional class and surface type combinations.

1.3 Literature Review

1.3.1 Pavement Management

Pavement management is the effective and efficient directing of the various activities like maintenance and repair of a network of roadways, involved in providing and sustaining pavements in an acceptable condition. The objective of pavement management is to obtain the best possible values for the available funds, and to provide safe, economical, and comfortable transportation system. Pavement management includes all phases of planning, programming, budgeting, analysis, design, construction, and research. Pavement management is divided into two levels, network level and project level. Network level management process deals with the planning, programming, and budgeting. It identifies the fund needs, prioritizes the needs, and determines the future impact of various funding scenarios on condition of the pavements. Project level management deals with the detailed and technical information related to designing a treatment for the pavement sections. At the project level, the best possible strategy for a pavement section within imposed constraints is determined [9].

1.3.2 Pavement Management System

Pavement Management System is a computerized decision support system that helps evaluate pavement maintenance and rehabilitation strategies based on the forecasted values of pavement attributes, subject to predetermined criteria and constraints. A primary objective of a PMS is to find cost the effective strategies that provide the recommendations for the level of service desired [9]. A structured PMS enables pavement managers and public works personnel to retrieve the inventory and other information stored in the database and assists in making decisions regarding the planning of investments, design, construction, maintenance, rehabilitation, and abandonment of the pavement. It supports the decisions about fund allocation, maintenance, and rehabilitation using rational procedures with quantified attributes and criteria. Pavement management systems also provide information on the current and future conditions of the pavements. Generally, the PMS includes components such as centralized database, analytical tools and reporting tools [5].

Centralized Database

The database forms the heart of the Pavement Management System [9]. All the inventory and condition assessment data, analysis and reporting tools which are used for decision making, are connected to the database.

The inventory provides information on the size of the network, locations, and basic information about the network. Inventory is generally a set of data that is needed by the PMS as a decision support tool for the managing pavements. An important part of the inventory is dividing the network into management sections. Inventory typically also provides information about the location and interconnectivity of each section of the pavement, size of the facility, etc. Data stored in the inventory is selected to provide enough information to provide effective management. Minimum data required for each section generally includes location, size, material type, usage level, year of construction, or year of last major repair [10].

Condition assessment provides information about the condition of pavement sections. Condition data is generally converted into the indices so that it can be used in quantifying changes in condition, predicting future changes in condition and establishing condition levels at which various maintenance and treatments should be applied. A condition index can be formed from the data available on type and severity of distress, skid resistance, ride quality, structural integrity, functional adequacy and other performance measures of a pavement section [11].

Other data required for decision making like unit costs for different treatments, parametric data for performance equations, etc. are also included in the database. The data in the database is updated regularly to provide reliable decisions.

Analysis Tools

Analysis tools are core parts of a PMS and are used to analyze data in the database that help in decision making. The quality of decision support from a PMS depends on the analysis tools used. Various analysis tools such as needs analysis, scenario analysis, etc. are used for the decision making. Needs analysis gives the information about pavement needs in terms of maintenance and rehabilitation treatments, the appropriate time to apply the treatments to keep the sections above service levels and the funds required without considering financial constraints [11]. The scenario analysis helps determine funds needed to provide the desired level of service, prioritize sections needing treatment if funds are constrained and evaluate the alternative treatments based on the impact of maintenance and treatments on pavement condition for different funding levels [11]. Predicted future condition of the pavements, estimated remaining life of the pavements and predicted fund needs are all used in the needs and the scenario analyses.

Performance prediction models and economic analysis tools are included in the analysis tools. Performance prediction models are used to predict performance of the pavement. A performance model is an equation that predicts the performance of a pavement section or estimates its condition in the future. Predicting the future condition helps identify when the treatments are required to maintain the system above the desired services level. The effect of different kinds of maintenance and rehabilitation actions on future condition of the pavement sections also can be assessed. Condition and cost information can assist in the selection of optimal treatments that can maintain a balance between the cost and performance. Prediction models are also used to calculate the remaining life of pavement sections [5].

Reporting Tools

Reporting tools provide the information from various analyses in the form of text and graphical formats. These reports are used in decision making for the pavement network. Various reports for the inventory, condition assessment, need analysis, scenarios analysis, etc, can be generated with this tool [5].

1.3.3 Prediction Models

Prediction models which are used to forecast the changes in the condition over some future time period can be classified into the following categories [5, 7, 8, 12]:

1) Mechanistic Models: Mechanistic models are based on the principles of mechanics and predict the pavement mechanistic responses like deflection, stresses or strains based on material properties, and environmental conditions. The complexity of the pavements and the large number of factors involved in the prediction makes this type of model difficult to use in the network-level PMS decision support analyses.

2) Empirical Models: In empirical models the dependent variable or condition can be related to one or more independent variable such as age of the pavement, loadings applied, layer thickness, etc, by regression analyses. Empirical models are based on the observed condition data or inspection data to predict the pavement performance. These models can only be developed with reasonable reliability when a long term database

with pavement performance data has been populated. They can only be used to predict the condition of sections similar to the ones on which the empirical model was developed.

3) Mechanistic-Empirical Models: The mechanistic-empirical model is the combination of the mechanistic and empirical models and uses pavement mechanistic responses as well as available data to predict the performance. In this model, a response parameter calculated with a mechanistic model is related to a measured structural or functional deterioration through regression equations.

4) Probabilistic Models: Probabilistic models predict the probability of the change in condition at any given time. The probabilistic models predict a range of values for the dependent variable indicating the variability in the projected pavement condition.

5) Bayesian Models: Bayesian models are developed by combining the observed data and experience using Bayesian statistical approach. Bayesian models are initially based on subjective data and then modified as the actual data becomes available.

The first three types of models are deterministic models and they predict a single value of condition or the time to reach a designated condition. These models are used for predicting the structural, functional, or damage performance of a pavement. The deterministic type of models can be used in the network level Pavement management system since much technical and detailed data is not required to develop these models. On the other hand, the probabilistic and Bayesian type of models, which require detailed and technical information regarding the pavement, are used in a network level PMS depending upon the agency requirements.

1.3.4 The MTC Pavement Management System

In this research, the Metropolitan Transportation Commission Pavement Management System (MTC-PMS) software (StreetSaver©) developed by the Metropolitan Transportation Commission (MTC) located in Oakland, California is used for the study. The MTC has supported the development, programming and modification of the PMS for about 25 years. The Metropolitan Transportation Commission-Pavement Management System is a pavement decision support tool developed for local agencies [13].

Typical data included in the MTC-PMS inventory includes location, functional class, surface type, usage, length, width, date of construction, condition data, maintenance and rehabilitation data, etc. Location gives the information about the location of a section with respect to some reference system or benchmark. Functional class represents the importance and the type of road based on volume and type of traffic. Surface types give the information about the type of surface of the sections [13].

The MTC-PMS uses four major functional classes: arterial, collector, residential/local and other based on volume and type of traffic. Arterial type of functional classification represents roads with moderate or high-capacity traffic whereas collector type of functional classification represents roads with low or moderate-capacity traffic and residential type of road represents roads with lower traffic levels which are not included in arterial or collector. The MTC-PMS uses six pavement surface types asphalt concrete (AC), portland cement concrete (PCC), asphalt concrete over asphalt concrete (AC/AC), asphalt concrete over portland cement concrete (AC/PCC), surface treatment (ST) and gravel (G); however, no analysis is supported for roads with gravel surfaces. The condition index used in the MTC - PMS is the Pavement Condition Index (PCI) which is based on the distress data obtained from walking surveys [14]. The PCI ranges from 0 to 100 where 100 indicate the best possible road conditions and 0 indicates very poor conditions.

MTC uses deterministic performance prediction models to predict the future PCI values of the pavement sections. Table A-1 gives the alpha (α), beta (β) and rho (ρ) regression coefficients that are currently used to predict the performance of the pavement sections in the MTC-PMS program. Table A-2 and Table A-3 in Appendix A give the regression coefficients for the regression equations for PCI increase due maintenance treatment such as crack seal, crack seal and surface seal, crack seal, patch and surface seal, and crack seal and localized for all asphaltic surface types and Portland Cement Concrete Surface Types [15]. These equations are used in the MTC-PMS to predict the change in PCI of pavement sections for different treatments. They are used with the performance equations to predict the condition after treatment, to calculate the remaining life of pavement sections after treatment and to evaluate the alternate pavement maintenance and rehabilitation strategies.

The PCI increase and post treatment condition data available from the MTC databases, which are used in the study, is composed mostly of pavement sections with AC and AC/AC surface types. Also, most of the preventive maintenance treatment data available are for slurry seal, cape seal and crack seal type of treatments. Hence, the equations to predict the PCI increase due to treatment and PCI loss/year after treatment were developed for slurry seal, cape seal and crack seal treatments with pavement surface types of AC and AC/AC.

CHAPTER II

DEVELOPMENT OF PREDICTION MODELS TO DETERMINE INCREASE IN CONDITION AND RATE OF DECREASE IN CONDITION AFTER TREATMENT

The MTC-PMS databases include extensive performance and historical data such as type of distress, severity of distress, and calculated PCI values over time. However, the MTC – PMS databases do not include information on pavement material properties, pavement layer thickness, traffic loading and environmental conditions that would be needed to calculate stresses, strains and deflection. On the other hand the MTC-PMS databases include condition information, date of construction, and maintenance activities. The available data can be used to develop PCI increase models and PCI loss models by using empirical models but cannot support mechanistic or mechanistic-empirical models. Further the equations developed are used to quantify the impact of the various treatments on the pavement condition for the use in the MTC - PMS which uses deterministic equations. Hence, deterministic empirical models are used to develop the prediction equations. The empirical models for the increase in condition for a treatment and decrease in condition per year after treatment are related to condition before applying treatment by regression analysis. The goal of the regression analysis is to obtain reasonable prediction models for use in the MTC-PMS StreetSaver decision support model, for use by local agencies in the San Francisco Bay Area.

To determine the effect of various attributes on PCI increase value and PCI loss value after treatment the data set are grouped into subsets such that the data in each subset have some common factors like functional class or surface type. Using this technique, data having similar maintenance treatments such as slurry seal, cape seal and crack seal are grouped together and the regression analysis is completed on each group generally called families in PMS.

2.1 Extraction of Data

The MTC – PMS databases for several agencies in the San Francisco Bay Area are stored as a backup file. The databases include inventory data for all the pavement sections in each network. The record for each section is uniquely identified by its 'street ID' and the 'section ID'. The backup file is attached to MYSQL which is a relational database management system that uses Structured Query Language [16]. The backup file can be attached to the MYSQL by enterprise manager which is an administrative tool for Microsoft SQL Server 2000© [17]. By connecting the backup file to MYSQL the various data sets from the database such as inspections, treatments, condition, etc. are assessed.

The data is extracted from the MTC-PMS databases for each street ID, section ID combination with their functional class, surface type, year of construction, the date and PCI value at inspection, the year and the type of the treatment, and overlay code. A query to extract data is run for all the above databases, and the desired results are exported to Microsoft Excel.

The data is sorted based on following three combinations:

1) Inspection – Treatment – Inspection

2) Inspection – Treatment – Inspection – Inspection

3) Inspection – Treatment – Inspection – Inspection - Inspection

The data sets that have inspection and treatments in this order are used for the analysis. The first combination is used to determine the PCI Increase after treatment. The other two combinations are used to determine PCI loss/year after treatment. The data is sorted from the extracted data such that for a particular section there are two or more inspections after treatment. Table 1 shows the databases and number of datasets used for the analysis.

Table 1: Database used to develop the prediction equations for PCI Increase with treatment and PCI loss/year after treatment

Sr. No	District	No. of Sections used for Analysis	
		PCI Increase	PCI Decrease / Yr
1.	Antioch	160	76
2.	Benicia	92	52
3.	Emeryville	37	-
4.	Freemont	1884	196
5.	Lafayette	96	10
6.	Morgan Hill	131	33
7.	Mountain view	6	6
8.	San Mateo	104	-
	Total	**2510**	**373**

To see the effect of various attributes on PCI increase values and PCI loss values after treatment the extracted data is further grouped into subsets such that the data in each subset had some common factors like functional class, surface types, etc. Then prediction equations are developed for the different groups. Using this technique sections having similar maintenance treatments such as slurry seal, cape seal and crack seal are grouped into families, and the regression analysis is completed on each family. The groups are further grouped based on the functional classification like arterial, collector and residential/local and surface type like asphalt concrete (AC) and overlaid asphalt concrete (AC/AC) to see the effect of different groupings on PCI increase and PCI loss values.

2.2 Illustration of PCI Increase and PCI Loss/Year for a Section

The PCI increase values and PCI loss/year values are calculated for all the pavement sections for which adequate inspection and treatment data are stored in the databases. The calculation of PCI increase value and PCI loss/year value for a section is shown in Figure 1. Figure 1 shows a sample section from the dataset, as extracted in section 2.1. The figure shows the effect of maintenance treatment on a pavement section. The condition index (PCI) is plotted against the date on which the maintenance and inspections were conducted. The points A, B, E, F and G in the figure are the points where regular inspection of the pavement section was completed. They represent the PCI values calculated based on the distress data found during the inspection. The point C is the PCI projected to the date of treatment which is discussed further in section 2.3. When a treatment is applied, there is an increase in the condition due to the application of a treatment. Point D indicates the condition of the section immediately after treatment. The difference between Point D and point C gives the PCI increase value. Because there is normally a delay between the date of maintenance and the subsequent inspection, the value for D must be projected backward from the PCI value from the inspection at E.

The difference in the condition of point E and F and F and G divided by the time lapse between them gives the PCI loss/year after treatment.

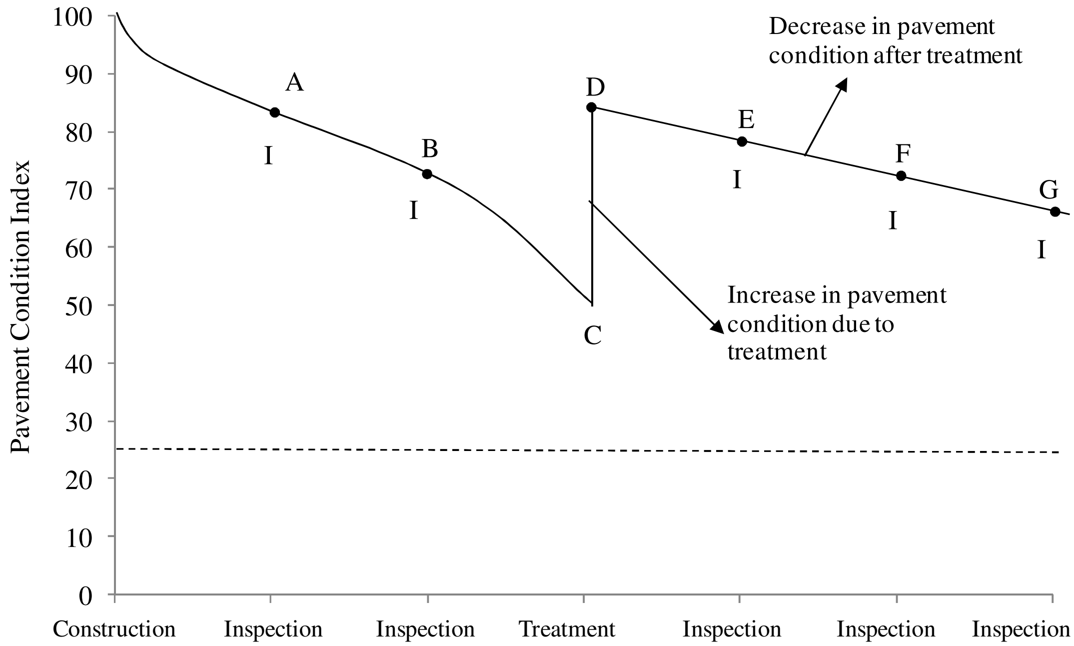

Figure 1: Deterioration curve for a management section before and after a treatment is applied

2.3 Research Methodology

The PCI Increase value is calculated by subtracting the PCI projected just before the treatment from the PCI projected immediately after the treatment. The PCI projected value is calculated based on section 2.3.3. The PCI loss/year value is calculated by subtracting the PCI observed value for two consecutive inspections after the treatment. The PCI Increase value and PCI loss/year value is calculated for all the sections for which inspection and treatment data is available.

2.3.1 Hypothesis

The objective of the thesis is to develop equations that can be used to predict the PCI increase value as a function of condition prior to treatment (PCI before treatment), and PCI loss/year value as a function of condition prior to treatment (PCI before treatment) and number of years to the first post treatment inspection. The development of the prediction equations is based on the assumption that a relationship exists between the PCI increase values and the PCI before treatment, PCI loss/year values and the PCI before treatment, and PCI loss/year values and the number of years to the first post treatment inspection. In other words, if the relationship does not exist, then the equation cannot be developed to predict PCI increase values and PCI loss/year values. The research methodology is therefore based on the following hypothesis:

Null hypothesis, H_o: Relationship does not exist between PCI increase values and the PCI before treatment, PCI loss/year values and the PCI before treatment, and PCI loss/year values and the number of years to the first post treatment inspection

Alternate Hypothesis, H_A: Relationship exists between PCI increase values and the PCI before treatment, PCI loss/year values and the PCI before treatment, and PCI loss/year values and the number of years to the first post treatment inspection

Based on the hypothesis, it can be stated that a prediction equation can be developed if the null hypothesis is rejected, else, no relationship is said to exist between the variables. To develop the equations, the PCI Increase values are plotted as a function of condition prior to treatment. Regression analysis is conducted and the best fit equation is selected based on statistics such as R^2, *t*-statistics and *F*-statistics. Similarly the prediction equations for PCI loss/year value are developed as a function of condition prior to treatment and the number of years to the first post treatment inspection. Matlab and Minitab are used to develop the equations and calculate selected statistics.

2.3.2 Regression Analysis

Regression analysis is a statistical tool for the investigation of the relationships between response and decision variables. In regression analysis, the response variable is expressed as a function of decision variables as follows [17].

$$\begin{aligned} Y &= \hat{Y} + e \\ \hat{Y} &= f(x) \end{aligned} \tag{1}$$

where, Y is the actual response, $\hat{Y}$ is the estimated response, x is the decision variable, e is the model error or residual and function f can be a polynomial of any order. The general form of the first and the second order polynomial can be expressed as

$$Y = \theta_0 + \theta_1 x + e \tag{2}$$

$$Y = \theta_0 + \theta_1 x + \theta_2 x^2 + e \tag{3}$$

where, θ_0, θ_1, θ_2 are the unknown coefficients to be estimated.

Ordinary Least Square Regression

In ordinary least square regression, the estimates of unknown coefficients in the polynomials are evaluated using the least squares estimation technique [17]. In the least square method, unknown estimates are obtained by minimizing the sum of the square of errors, SS_{E-O}

$$SS_{E-O} = \sum_{i=1}^{k} e_i^{\ 2} \tag{4}$$

The estimates of coefficients obtained by solving Equation (4) are unbiased estimators under the assumption that the errors, e_i, are normally distributed and statistically independent with zero mean and constant variance (homoscedasticity). In the assumption of homoscedasticity, the variance of residual error is assumed to remain constant over the entire range of data. If the assumption of homoscedasticity is violated, then the estimates of regression coefficients will be biased and the corresponding standard errors of the regression coefficients will be inefficient (overestimated or underestimated) [17].

The assumption of homoscedasticity can be checked using scatter plots [18]. Figure 2 shows the scatter plot for PCI increase due to slurry seal treatment with respect to PCI before treatment. The scatter plot display a "funnel shape," which indicates that the assumption of homoscedasticity for ordinary least square regression analysis is violated. Violation of homoscedasticity occurs when the magnitude of the dependent is correlated with the variance of the independent [18]. It is observed in Figure 2 that the variance in the data is not constant over the ranges of PCI before treatment. For instance, for the lower values of PCI before treatment the spread of the data is very high as compared to the spread for higher PCI before treatment values. Similar to slurry seal treatment, the scatter plots for cape seal and crack seal treatments were checked and it was observed that the assumption of homoscedasticity is violated. In such situations, where the assumption of homoscedasticity is violated weighted regression is recommended [19].

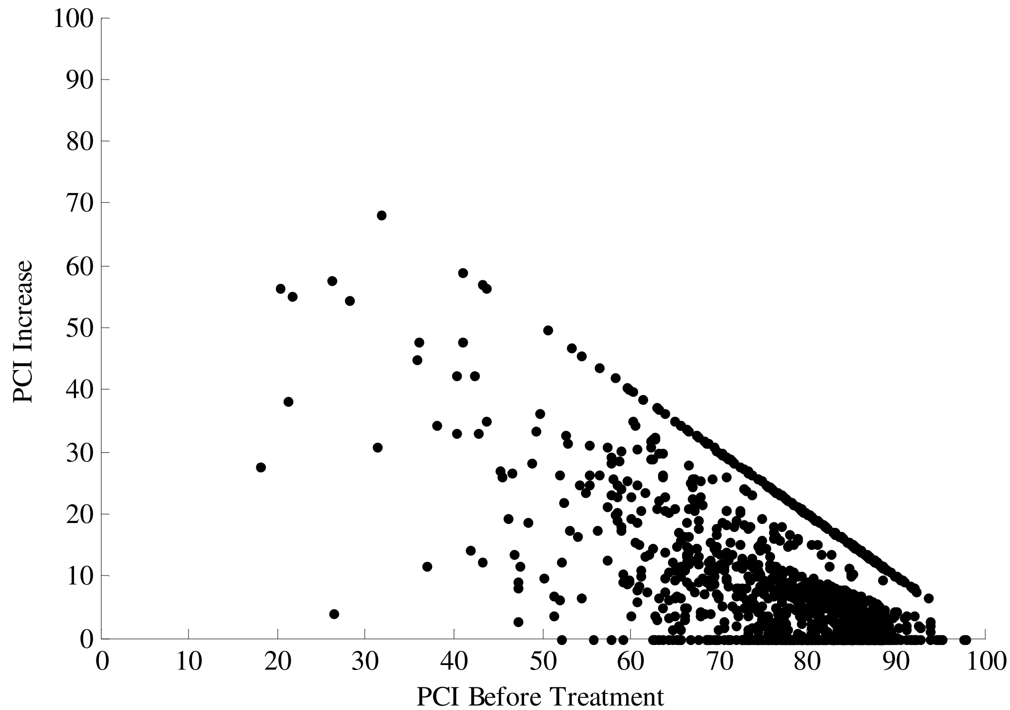

Figure 2: Scatter plot for PCI before treatments vs. PCI increase for slurry seal

Weighted Least Square (WLS) Regression

In WLS regression analysis, while estimating the regression coefficients, the violation of the homoscedasticity assumption is compensated by assigning the lower weights to the data sets with large variance and higher weights to the data points with small variances. The size of the weight indicates the precision of the information contained in the associated observation [19]. That is, cases with greater weights contribute more to the fit of the regression equation. First step in the WLS regression is to compute weights of each data points which are typically considered to be inversely proportional to the variance

[19]. In Figure 2 it is observed that the spread in the data is proportional to the PCI values before treatment i.e. spread decreases with increase in PCI before treatment values. Since the range is constrained between 0 and 100, the variance of any data point would be proportional to $(100\text{-PCI})^2$. The weight of each data point then can be computed as

$$w_i = \frac{1}{\left(100 - \mathrm{PCI}_i\right)^2} \tag{5}$$

Once the weights are assigned to the data points, the unknown coefficients in the polynomials can be estimated by minimizing the sum of the square of errors, SS_{E-W}.

$$SS_{E-W} = \sum_{i=1}^{k} w_i e_i^{\,2} \tag{6}$$

Statistical Validation

Once the regression model is developed, it is necessary to check the model accuracy and adequacy. In this research statistics including coefficient of determination (R^2), F-statistics (F_o) and t-statistics (t_o) are used. The coefficient of determination (R^2) is an overall measure of the fit of the model to the data [17]. R^2 measures the proportion of variation in the response that is accounted for by the model. The value of R^2 is between 0 and 1, where 1 represents the best fit. In addition to R^2, it is necessary to determine significance of the regression equation, whether a relationship exists between the response variable and decision variables [17]. The significance of regression is determined using F-statistics. In the F-statistics, the basic null hypothesis is that all the regression coefficients in the developed equation are zero (H_o: coefficient$_1$ = coefficient$_2$ = 0) i.e. no relationship exists between decision and response variable. The alternate hypothesis is that all the regression coefficients in the developed equation are not equal to zero (H_A: coefficient$_1$ $\neq$ coefficient$_2$ $\neq 0$) i.e. a relationship exists between the decision and response variables. Based on the hypothesis the model can be termed as significant if the null hypothesis is rejected. The null hypothesis is rejected if the calculated F_o is greater than the critical value, $f_{\alpha,k,n-p}$ taken from the table of F-statistics, where α is the significance level, k is the number of decision variables, n is the number of data sets used for regression analysis and $p = k + 1$ [17]. Thus, the null hypothesis of the research methodology that a relationship does not exist, between PCI increase and PCI before treatment, PCI loss/year and PCI before treatment and PCI loss/year and number of years to first post treatment inspection, can be rejected if $F_o > f_{\alpha,k,n-p}$. If $F_o < f_{\alpha,k,n-p}$, the null hypothesis of the research methodology cannot be rejected, and it can be stated that the relationship does not exist. Further to test the significance of the individual coefficients in the developed polynomial equation and decide the order of the polynomial to be used in the prediction equation, *t*-statistics are used. In the *t*-statistics, the basic null hypothesis is that each regression coefficient in the developed equation is zero (H_o: coefficient = 0) i.e. the regression coefficient is insignificant. The alternate hypothesis is that each regression coefficient in the developed equation is not equal to zero (H_A: coefficient $\neq 0$) i.e. the regression coefficient is significant [17]. Based on the hypothesis the variables can be termed as significant if the null hypothesis is rejected. If we reject the null hypothesis i.e. some or all the coefficient in the higher order equation are insignificant, a lower order equation should be developed. The null hypothesis can be rejected if the absolute value of the calculated t-statistics $|t_o|$ is greater than the critical value, $t_{\alpha/2,n-p}$ taken from the table of t-statistics, where α, n and p are the same as used for F-statistics.

2.3.3 Calculation of PCI Projected

The PCI values at the point just before treatment and immediately after treatments, point C and D as shown in Figure 1, are not available in the database and are projected from the inspections before the treatment and after the treatment respectively. The projected condition is individualized for each section based on the observed performance. At every inspection the PCI projected values are adjusted such that they are equal to the PCI value observed. If the PCI observed does not match the projected condition, CHI or SHIFT value (known as the projection modifiers) are adjusted to force the PCI projected value to match the observed value for each management section. The CHI value is normally used to bend the projected PCI curve through the latest observed PCI value using Equation (1). The SHIFT value is modified to show the effect of the application of treatment. This provides an increase in the pavement condition due to application of maintenance treatment. Various parameters like CHI, SHIFT, AGE, PCI, PCI family and AGE inspection are used for calculation of PCI projected [15].

The Equation (7) is a sigmoidal equation used to calculate the projected PCI value to predict the pavement condition in terms of PCI as a function of age.

$$\mathrm{PCI} = 100 - \frac{\mathrm{CHI} \times \rho}{\left[\ln\left(\frac{\alpha}{\mathrm{AGE} - \mathrm{SHIFT}}\right)\right]^{\frac{1}{\beta}}} \tag{7}$$

where, PCI is the projected PCI value at some value of AGE, CHI is the PCI bending multiplicative adjustment factor, α is the regression constant that controls the age to which the curve is asymptotic, β is the regression constant that controls how sharply the curve bends, ρ is the regression constant that controls the age at which the inflection point in the curve occurs, SHIFT is the age shifting additive adjustment, AGE is the age in time since construction to the time at which the PCI is to be calculated. The initial CHI and SHIFT values are set to be 1 and 0 respectively, and they are modified during the analysis. The CHI and SHIFT values in Equation (7) are adjusted based on Equation (8) and Equation (9) such that PCI observed is equal to PCI projected.

The alpha (α), beta (β) and rho (ρ) which are used to predict the condition of the pavement in future are known as projection parameters. These values were developed in previous research and were not evaluated in this study (Appendix A). They are regression constants from the family performance equations. These parameters are unique for different functional class/surface groups. By designating the functional class and surface types we designate which alpha, beta and rho values are used for the analysis.

Figure 3 shows the change in projected condition after an inspection based on adjusting the CHI value. Point A in the figure indicates the PCI value based on the family curve with CHI equal to 1. Point B indicates the PCI observed at the time of inspection. The CHI value indicated in the figure is calculated from Equation (8) and is used to bend the PCI projection curve through the PCI observed value, point B.

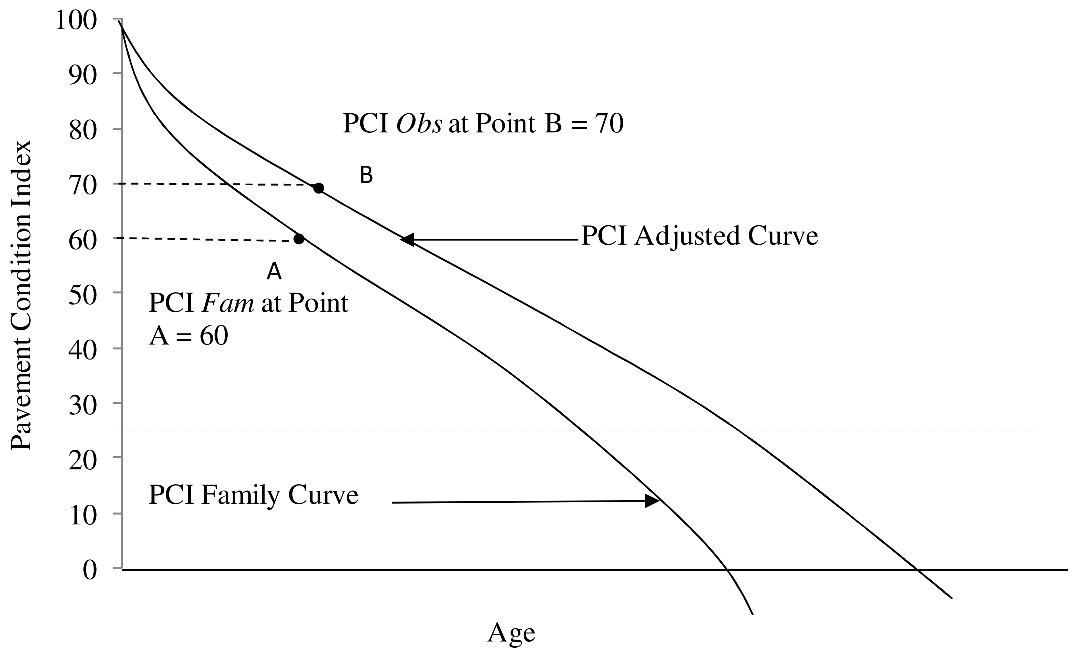

Figure 3: Change in the projected condition based on CHI

Figure 4 shows the change in projected condition after application of a treatment based on an adjusted SHIFT value. Point A in the figure indicates the PCI value before treatment. Point B indicates the PCI value after application of the preventive maintenance treatment. The SHIFT value indicated in the figure is calculated from Equation (9) and is used shift the projection curve after treatment to change the projected condition of the section to pass through the PCI value after treatment, point B.

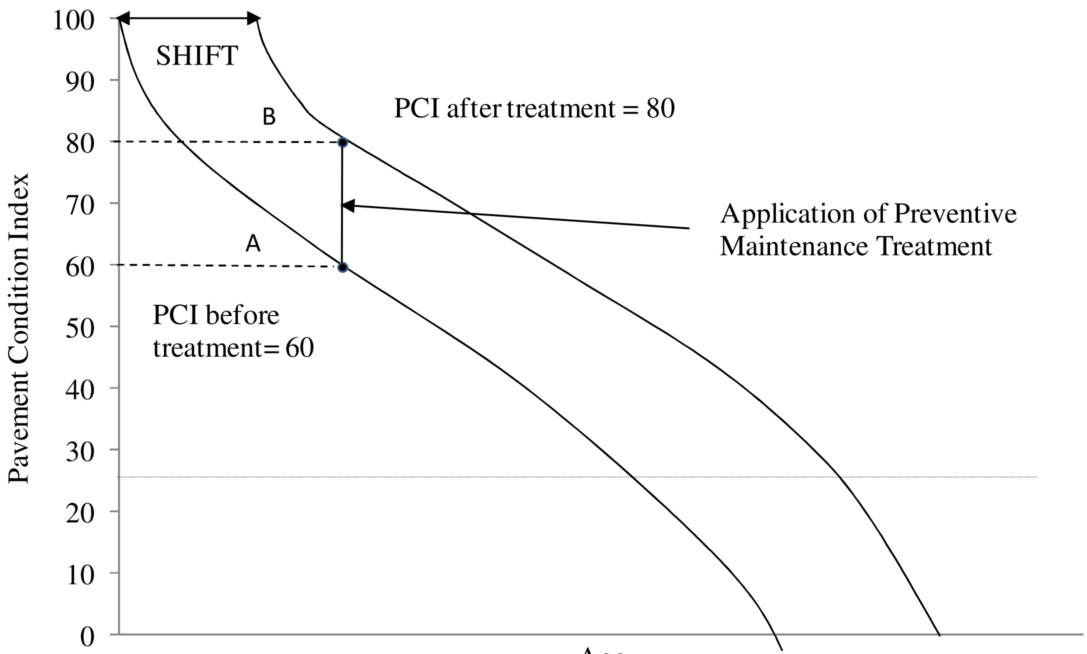

Figure 4: Change in the projected condition based on SHIFT

The CHI value is calculated as shown in Equation (8).

$$\mathrm{CHI} = \frac{100 - \mathrm{PCI}_{\mathrm{Obs}}}{100 - \mathrm{PCI}_{\mathrm{Fam}}} \tag{8}$$

where, CHI is the PCI bending multiplicative adjustment factor, $\mathrm{PCI}_{\mathrm{Obs}}$ is PCI value through which the curve is to pass i.e. PCI observed at inspection, $\mathrm{PCI}_{\mathrm{Fam}}$ is the PCI value from Family curves at the age of inspection. The $\mathrm{PCI}_{\mathrm{Fam}}$ value is calculated from Equation (7) with current CHI and SHIFT values and AGE as age of pavement at the inspection.

If the CHI calculated is within limits i.e. the CHI value is greater than 0.5 or less than 1.5, then the current CHI value is set equal to the calculated CHI value from

Equation (8), and the SHIFT value is unchanged. If the CHI value is not in that range, then a new SHIFT value is calculated. The new SHIFT value for projecting future condition which shifts the curve to force it to go through the observed PCI value at the time of inspection is calculated by subtracting the AGE at Inspection value from the AGE according to family curves. The new SHIFT value is calculated as shown in Equation (9) [15].

$$\text{SHIFT}=\text{AGE}_{\text{Fam}}-\text{AGE}_{\text{Insp}} \tag{9}$$

where, AGE_{Fam} is calculated based on the PCI value from the inspection based on prior CHI and SHIFT values and AGE_{Insp} is the age of the section at the time of inspection. AGE_{Fam} required in the above equation is calculated using the current values for CHI and SHIFT stored in the data set using Equation (10) [15].

$$\text{AGE}_{\text{Fam}}=\text{SHIFT}+\alpha e^{-\left(\frac{\text{CHI}\times\rho}{100-\text{PCI}_{\text{Insp}}}\right)^{\beta}} \tag{10}$$

AGE_{Insp} is the age of the section at the time of inspection is calculated using Equation (11) [15].

$$\text{AGE}_{\text{Insp}}=\text{DATE}_{\text{Insp}}-\text{DATE}_{\text{Const}} \tag{11}$$

where, $\text{DATE}_{\text{Insp}}$ is the date of inspection and $\text{DATE}_{\text{Const}}$ is the date of construction.

2.4 Determination of Equations for PCI Increase with Treatment

To determine the PCI Increase due to a treatment, the PCI value just before the treatment and the PCI values immediately after treatment are required, and Equation (7) is used to determine these values. The PCI increase values are plotted with respect to the PCI values before treatment. The weighted regression analysis is completed for different groups such as slurry seal, cape seal and crack seal generally called families in PMS for the 1st and 2nd order polynomials, and the best fit is decided based on statistics such as R^2, *t*-statistics and *F*-statistics [17, 18]. This equation is used to show the trend for PCI increase due to an applied treatment. In the tables of statistics, s is the estimate of error standard deviation of the developed equation. It gives the variability of PCI increase at a particular value of PCI before treatment. Low values of "s" indicate that the observed values of the predicted variable (PCI increase) fall close to the developed equation line, and large values of "s" indicate that the observed values may deviate considerably from the developed line. As compared to the variability of the data for PCI increase values which is spread between 0 to 70, the observed value of s is low for the developed equation. Further for each functional class surface type combination, the sections with 0 PCI increase value are neglected and regression analysis is carried out to see the effect of 0 PCI increase value on the developed equations. N_0 value in the subsequent figures indicates the number of section with 0 PCI increase values.

2.4.1 Slurry Seal

Slurry seal treatments are generally applied to the pavements with good condition values, with PCI values between 60 and 90, as a preventive maintenance to increase their service life by decreasing the overall deterioration. Figure 5 shows the results of weighted regression analyses to determine the PCI increase values for slurry seal treatments. The average value of PCI increase due to application of the slurry seal treatment is about 8. In this data set, the PCI increase values for all the sections in the slurry seal family are plotted with respect to PCI before treatment. Table 2 shows the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 2 also shows the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 399.163 > $f_{0.1,1,1628}$ = 2.71 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 374.914> $f_{0.1,2,1627}$ = 2.30 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The computed t-statistics for the coefficients in the second order equation are greater than $t_{0.05,1627}$ = 1.656 [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the second order equation is significant. Therefore, the data for slurry seal is fitted using a 2nd order polynomial equation shown in Equation (12).

$$Y = 0.004x^2 - 1.064x + 66.292 \tag{12}$$

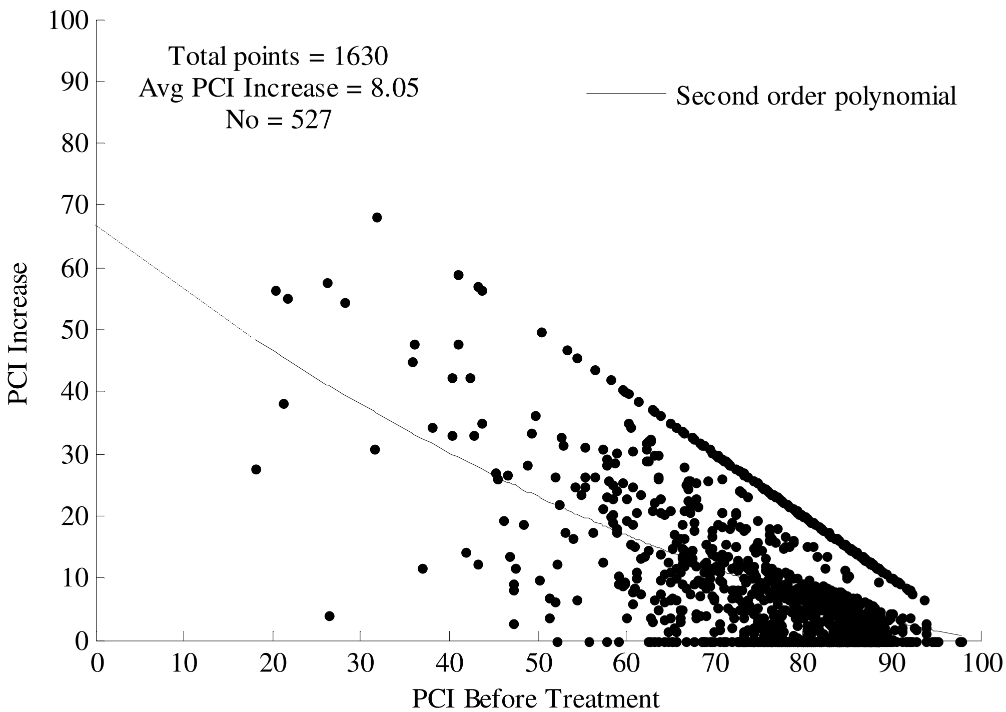

Figure 5: PCI increase equation for slurry seal treatments

Table 2: Coefficients of regression for slurry seal treatments

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	38.485	-0.392	-	0.373	399.163>2.71	0.196
t-statistics	|24.631|>1.656	|-21.914|>1.656	-			
2nd order	66.292	-1.064	4.023E-03	0.372	374.914>2.30	0.314
t-statistics	|8.139|>1.656	|-5.481|>1.656	|3.478|>1.656			

Figure 6 shows the results of weighted regression analyses conducted without considering the 0 PCI increase values. The average PCI increase value on excluding 0 PCI increase values is about 12. Table 3 gives the regression coefficients and the R^2, *F*-

statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance ($\alpha = 0.1$), the obtained F_0 value for the developed model is 519.904 > $f_{0.1,1,1101}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 349.842> $f_{0.1,2,1100}$ = 2.35 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The computed t-statistics for the coefficients in the second order equation are greater than $t_{0.05,1100}$ = 1.657. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the second order equation is significant. Therefore, the data for slurry seal excluding 0 PCI increase values is fitted using a 2nd order polynomial equation shown in Equation (13).

$$Y = 0.003x^2 - 1.039x + 69.464 \tag{13}$$

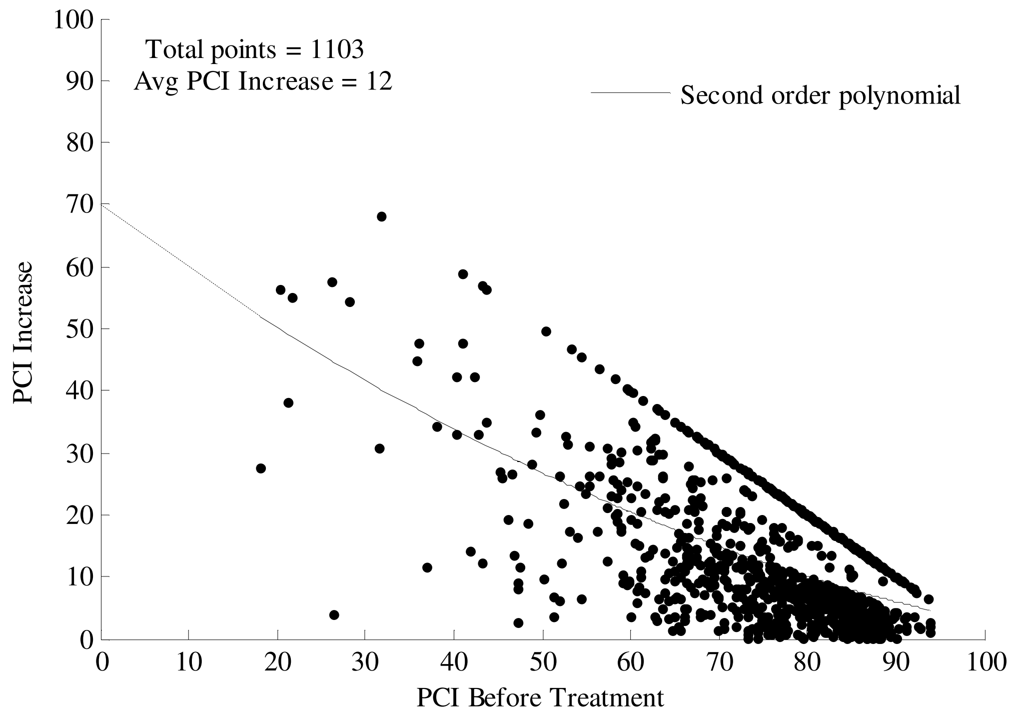

Figure 6: PCI increase equation for slurry seal treatments excluding points corresponding to 0 PCI increase

Table 3: Coefficients of regression for slurry seal treatments excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	47.702	-0.466	-	0.342	519.904>2.75	0.321
t-statistics	|21.948|>1.657	|-18.123|>1.657	-			
2nd order	69.464	-1.039	3.712E-03	0.341	349.842>2.35	0.389
t-statistics	|6.839|>1.657	|-3.956|>1.657	|2.193|>1.657			

Figure 7 shows the comparison of two models. The 90% prediction intervals are calculated using Minitab. The solid lines in the figure represent the mean and 90% prediction interval for the model developed for slurry seal considering the 0 PCI increase data sets. The dotted lines in the figure represent the mean and 90% prediction interval for the model developed for slurry seal excluding the 0 PCI increase data sets. In the figure it is observed that the two prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar, and the effect of 0 PCI increase values on the prediction trend can be neglected. Hence, the Equation (12), developed for slurry seal can be used to show the PCI increase trend for slurry seal family. Also, about 90% of the data in Figure 5 has PCI before treatment values ranging from 60 to 90, which is the range of PCI at which slurry seal treatments are expected to be applied.

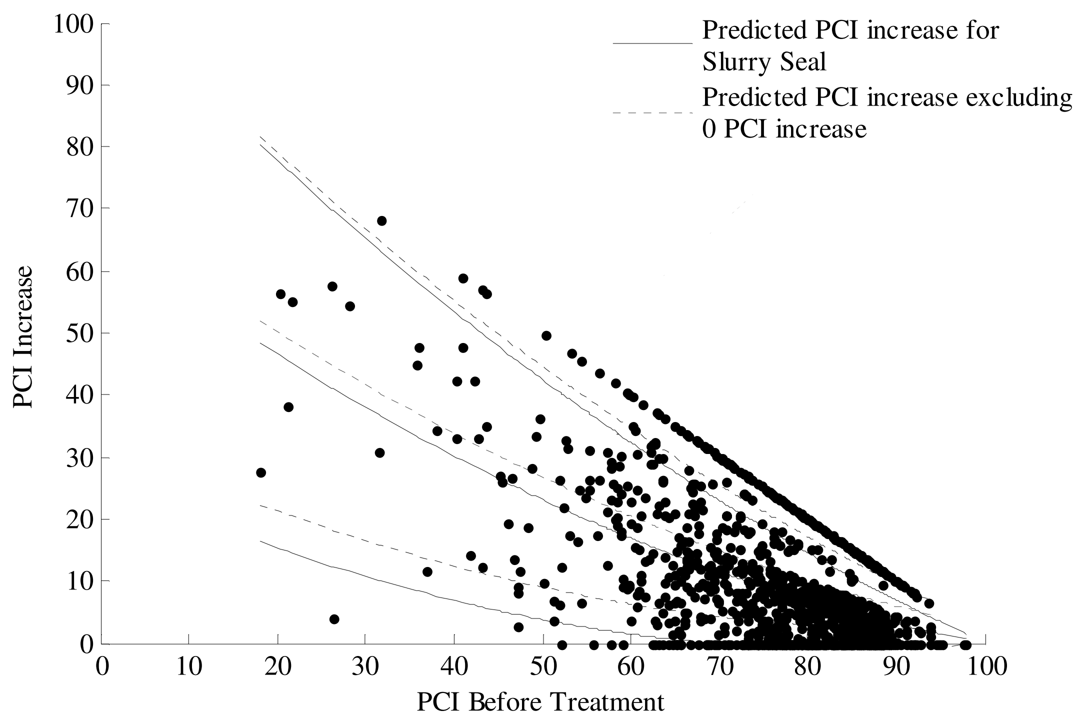

Figure 7: Mean and prediction interval for slurry seal type of treatment with and without data 0 PCI increase data sets

To see the effect of functional class and surface type, the slurry seal family can be further grouped in functional class and surface type families such as arterial AC, arterial ACAC, collector AC, collector ACAC, residential AC and residential ACAC. Table 4 gives the number of data sets used in analysis for each functional class surface type combination and the number of data sets without 0 PCI increase values.

Table 4: Number of data sets for PCI increase and 0 PCI increase for all functional class surface type combination for slurry seal

Functional Class - Surface Type	PCI Increase Data sets	Data sets with PCI Increase as 0
Arterial AC	51	4
Arterial AC/AC	19	0
Collector AC	79	7
Collector AC/AC	15	2
Residential AC	1147	393
Residential AC/AC	319	121
Total	1630	527

Figure 8 shows the results of weighted regression analyses to determine PCI increase for slurry seal treatments with functional class type arterial and surface type AC. Table 5 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 5 also shows the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 53.656> $f_{0.1,1,49}$ = 2.84 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 29.108 > $f_{0.1,2,48}$ = 2.44 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial. The R^2 values for the 1st and 2nd order polynomial equations are not much different which shows that the addition of the second order does little to improve the model. The computed t-statistics for the coefficients in the second order equation are not greater than $t_{0.05,48}$ = 1.679 [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics for the second order equation and conclude that the second order equation is not significant. Therefore, the data for slurry seal arterial AC is fitted using a 1st order polynomial shown in Equation (14).

$$Y = -0.765x + 72.796 \tag{14}$$

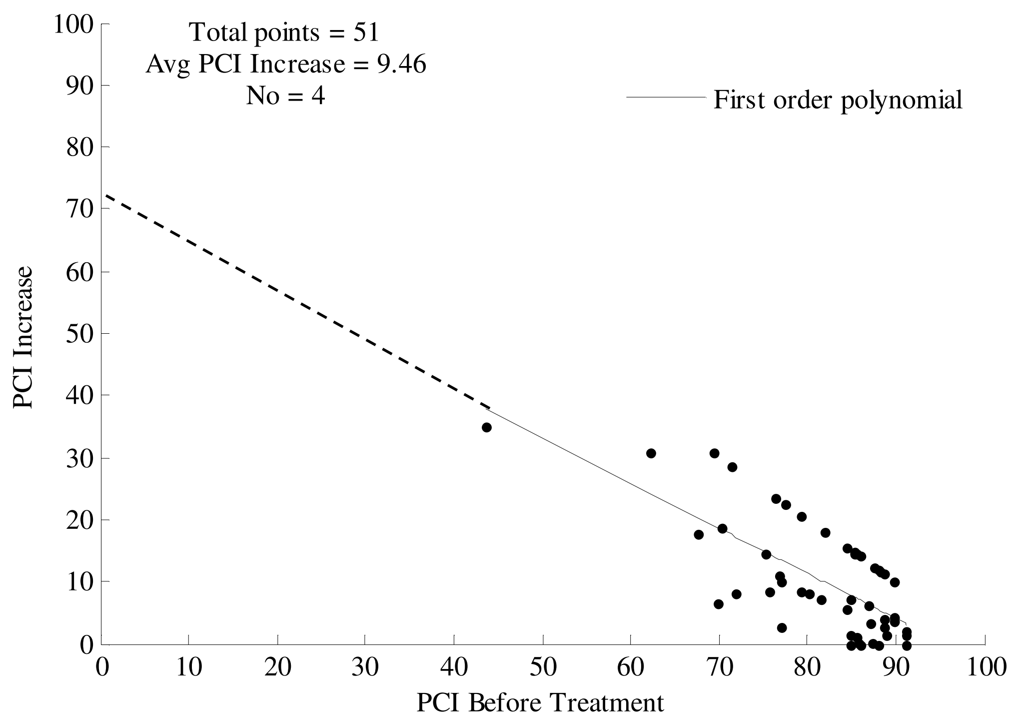

Figure 8: PCI increase equation for slurry seal treatments with functional class arterial and surface type AC

Table 5: Coefficients of regression for slurry seal treatments with functional class arterial and surface type AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	72.796	-0.765	-	0.380	53.656>2.84	0.428
t-statistics	|5.256|>1.679	|-4.858|>1.679	-			
2nd order	145.3	-2.613	0.011	0.384	29.108>2.44	0.434
t-statistics	|0.861|<1.679	|-0.337|<1.679	|-7.344E-03|<1.679			

As there are few data sets with 0 PCI increase value in this group, the analyses without considering the points with 0 PCI increase values is not conducted. Hence, Equation (12) developed for slurry seal arterial AC can be used to show the PCI increase trend for slurry seal family arterial AC family.

Figure 9 shows the results of weighted regression analyses to determine PCI increase for slurry seal treatment with functional class collector and surface type AC. The average PCI increase value for this group is about 11. Table 6 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 6 also shows the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance ($\alpha = 0.1$), the obtained F_0 value for the developed model is 103.657 > $f_{0.1,1,77}$ = 2.79 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 48.271 > $f_{0.1,2,76}$ = 2.39 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. However, the t-statistics show that the first and the second order coefficients are not significant in the second order polynomial equations i.e. the computed t-statistics are not greater than

$t_{\alpha/2,n-p}$, 1.666 [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics for the second order equation. Therefore, the data for slurry seal collector AC is fitted using a 1st order polynomial equation shown in Equation (15).

$$Y = -0.467x + 47.53 \tag{15}$$

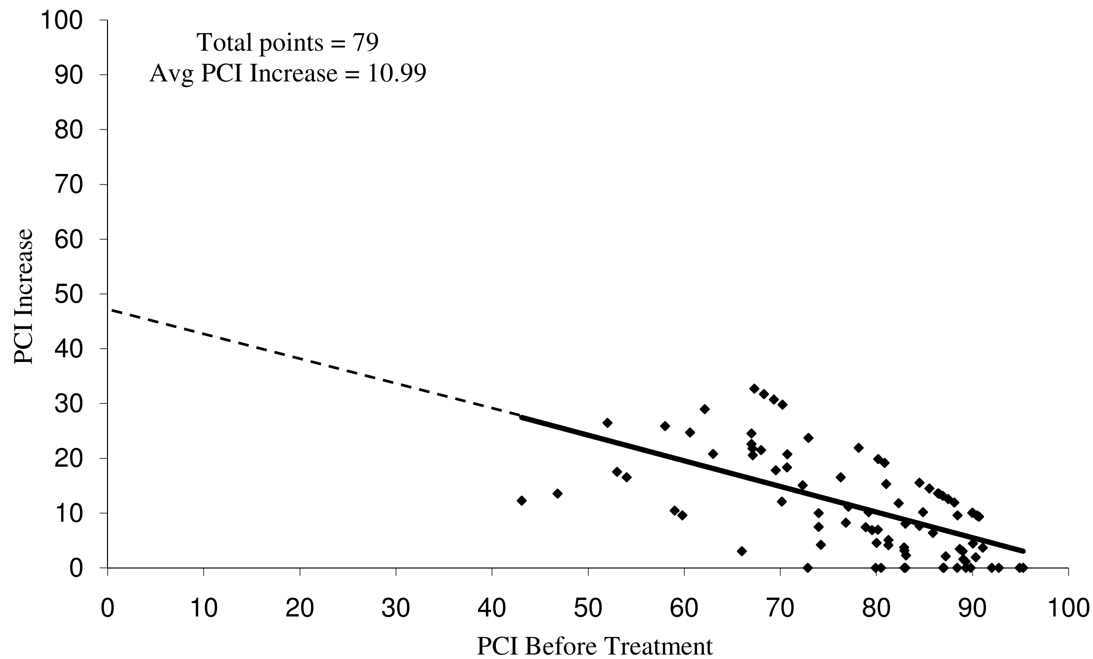

Figure 9: PCI increase equation for slurry seal treatments with functional class collector and surface type AC

Table 6: Coefficients of regression for slurry seal treatments with functional class collector and surface type AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	47.53	-0.467	-	0.334	103.657>2.79	0.371
t-statistics	|11.362|>1.666	|-10.73|>1.666	-			
2nd order	-22.82	1.518	-0.013	0.338	48.271>2.39	0.431
t-statistics	|2.763|>1.666	-|0.636|<1.666	|-4.123E-01|<1.666			

As the number of data sets with 0 PCI increase value in this group is small, the analyses without considering the data sets with PCI increase as 0 was not conducted. Therefore, the equation developed for slurry seal collector AC as shown in Figure 9 could be used to show the PCI increase trend for slurry seal collector AC family.

Figure 10 shows the results of weighted regression analyses to determine the PCI increase for slurry seal treatment with functional class residential and surface type AC. The average PCI increase value for this group is about 8. Table 7 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 7 also shows the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance ($\alpha = 0.1$), the obtained F_0 value for the developed model is 182.291 > $f_{0.1,1,1145} = 2.71$ [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 122.433 > $f_{0.1,2,1144} = 2.30$ [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. However, the *t*-statistics show that the second order coefficient in the second order polynomial equation is not significant i.e. the computed *t*-statistics is not greater than $t_{0.05,1144} = 1.657$ [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics for the second order coefficient of the 2nd order equation and conclude that the second order equation is not significant. Therefore, the data for slurry seal residential AC is fitted using a 1st order polynomial equation shown in Equation (16).

$$Y = -0.363x + 35.935 \tag{16}$$

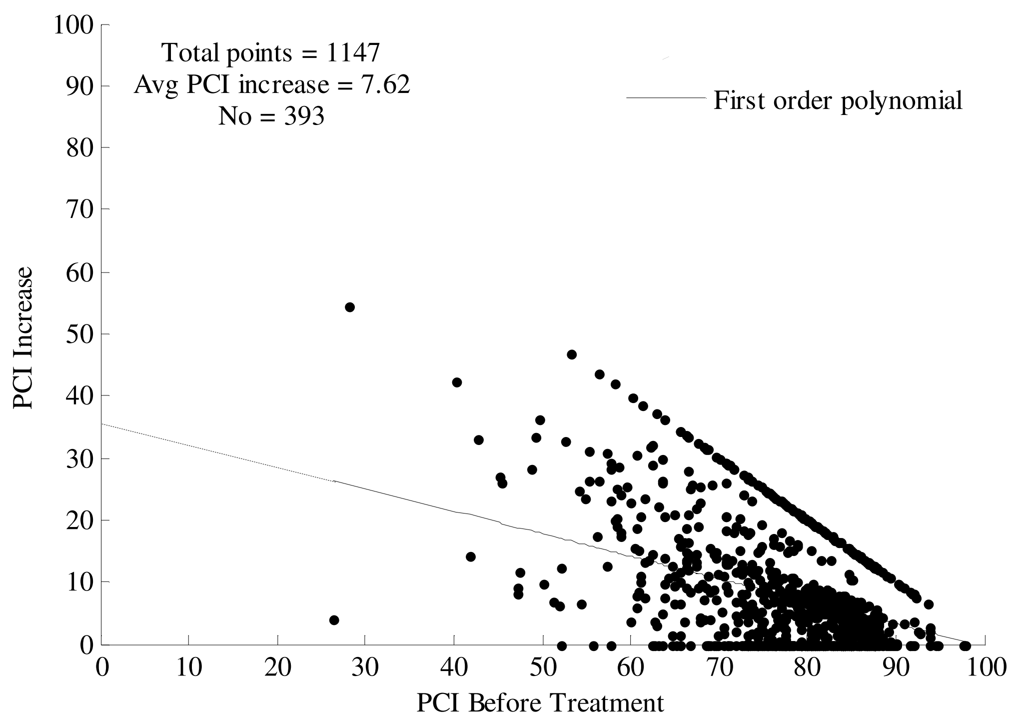

Figure 10: PCI increase equation for slurry seal treatments with functional class residential and surface type AC

Table 7: Coefficients of regression for slurry seal treatments with functional class residential and surface type AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	35.935	-0.363	-	0.372	182.291>2.71	0.137
t-statistics	|20.654|>1.657	|-18.314|>1.657	-			
2nd order	45.515	-0.590	1.339E-03	0.372	122.433>2.30	0.176
t-statistics	|4.024|>1.657	|-2.216|>1.657	|0.857|<1.657			

Figure 11 shows the results of weighted regression analyses conducted for slurry seal residential surface type AC family without considering the data sets with 0 PCI increase. The average PCI increase is about 12. Table 8 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 249.479 > $f_{0.1,1,752}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 139.170 > $f_{0.1,2,751}$ = 2.35 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for the 1st and 2nd order polynomial equations. However, the t-statistics show that the second order coefficient in the 2nd order polynomial equation is not greater than $t_{0.05,751}$ = 1.657 [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics for the second order coefficient of 2nd order polynomial equation and conclude that the 2nd order equation is not significant. Therefore, the data for slurry seal residential AC excluding 0 PCI increase values is fitted using a 1st order polynomial equation shown in Equation (17).

$$Y = -0.442x + 45.734 \tag{17}$$

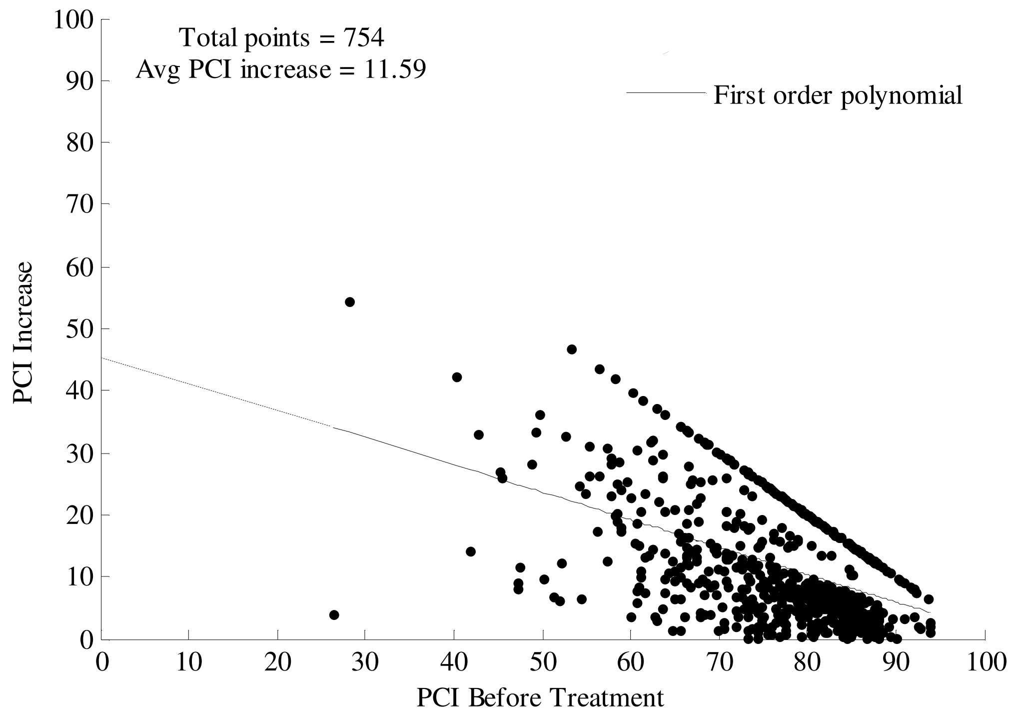

Figure 11: PCI increase equation for slurry seal treatments with functional class residential and surface type AC excluding points corresponding to 0 PCI increase

Table 8: Coefficients of regression for slurry seal treatments with functional class residential and surface type AC excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	45.734	-0.442	-	0.339	249.479>2.75	0.249
t-statistics	|17.110|>1.657	|-13.902|>1.657	-			
2nd order	58.138	-0.761	2.027E-03	0.339	139.170>2.35	0.270
t-statistics	|3.816|>1.657	|-1.965|>1.657	|0.827|<1.657			

Figure 12 shows the comparison of the two equations for residential AC with and without considering the 0 PCI increase values. The solid lines in the figure represent the mean and 90% prediction interval for the model developed considering the 0 PCI increase values for slurry seal residential AC family. The dotted lines in the figure represent the mean and 90% prediction interval for the slurry seal residential AC model developed by excluding the 0 PCI increase values. In the figure it is observed that the prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar, and the effect of 0 PCI increase values on the developed equation can be neglected. Therefore, Equation (16) can be used to show the trend in PCI increase values for slurry seal residential AC family.

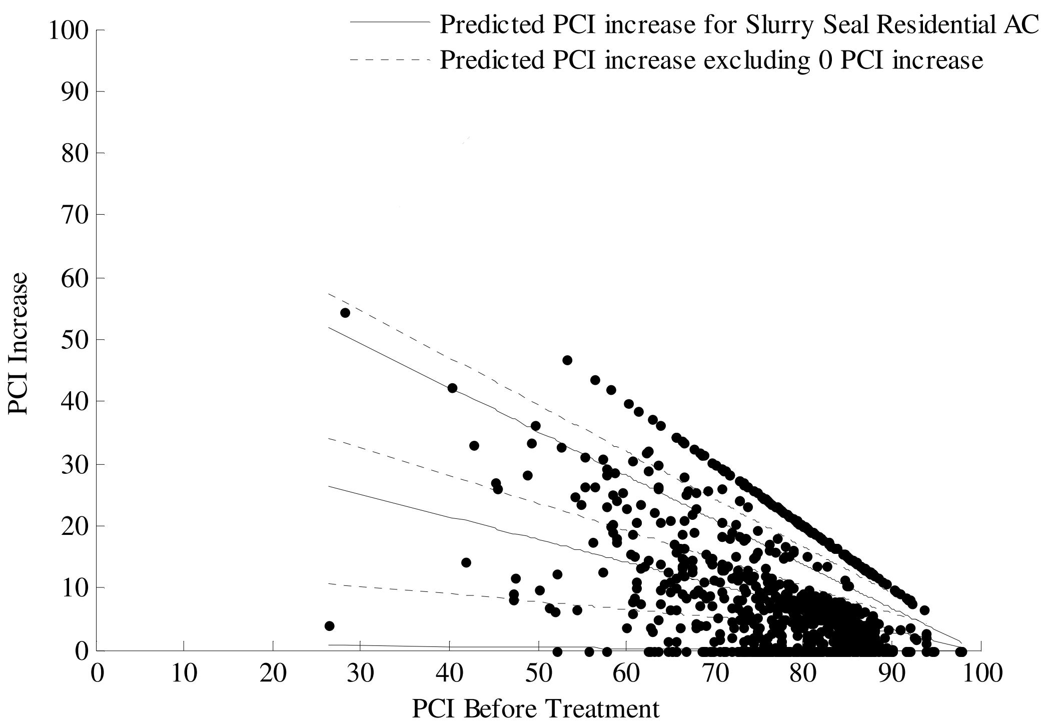

Figure 12: Mean and prediction interval for slurry seal residential AC family with and without data sets with PCI increase as 0

The number of data sets for functional class arterial and surface type AC/AC are only 19. Hence, the equation developed based on this data cannot be claimed to be reliable for predicting the PCI increase for slurry seal arterial AC/AC family. Figure 13 shows the PCI increase values for slurry seal arterial AC/AC family. The dashed and dotted lines in the figure show the mean and 90% prediction interval for the model for slurry seal in Figure 5. Since, most of the datasets for slurry seal arterial AC/AC fall in the prediction interval of slurry seal, it is recommended that the Equation (12) developed for slurry seal should be used to show the PCI increase trend for slurry seal arterial AC/AC family.

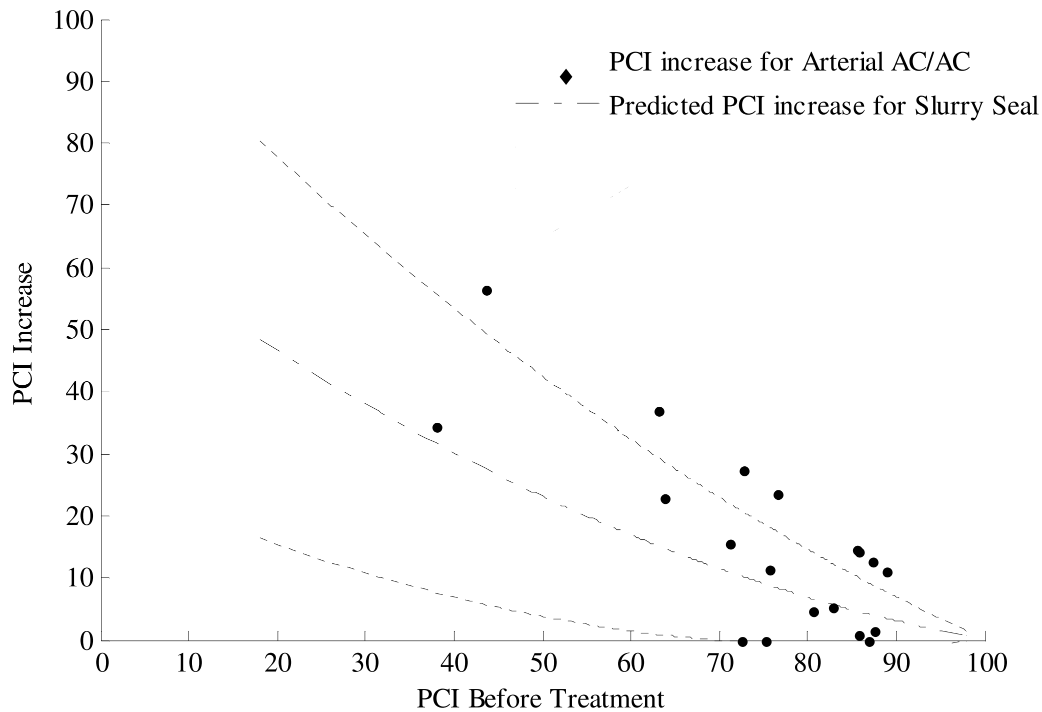

Figure 13: Slurry seal arterial AC/AC family and mean and prediction interval for slurry seal family for PCI increase

The number of data sets for functional class collector and surface type AC/AC are only 15. Hence, the equation developed based on this data cannot be claimed to be reliable for predicting the PCI increase for slurry seal collector AC/AC family. Figure 14 shows the PCI increase values for slurry seal collector AC/AC family. The dashed and dotted lines in the figure show the mean and 90% prediction intervals for the model for slurry seal in Figure 5. Since, most of the datasets for slurry seal collector, AC/AC fall in the prediction interval of slurry seal, it is recommended that the Equation (12) developed for slurry seal should be used to show the PCI increase trends for slurry seal collector AC/AC family.

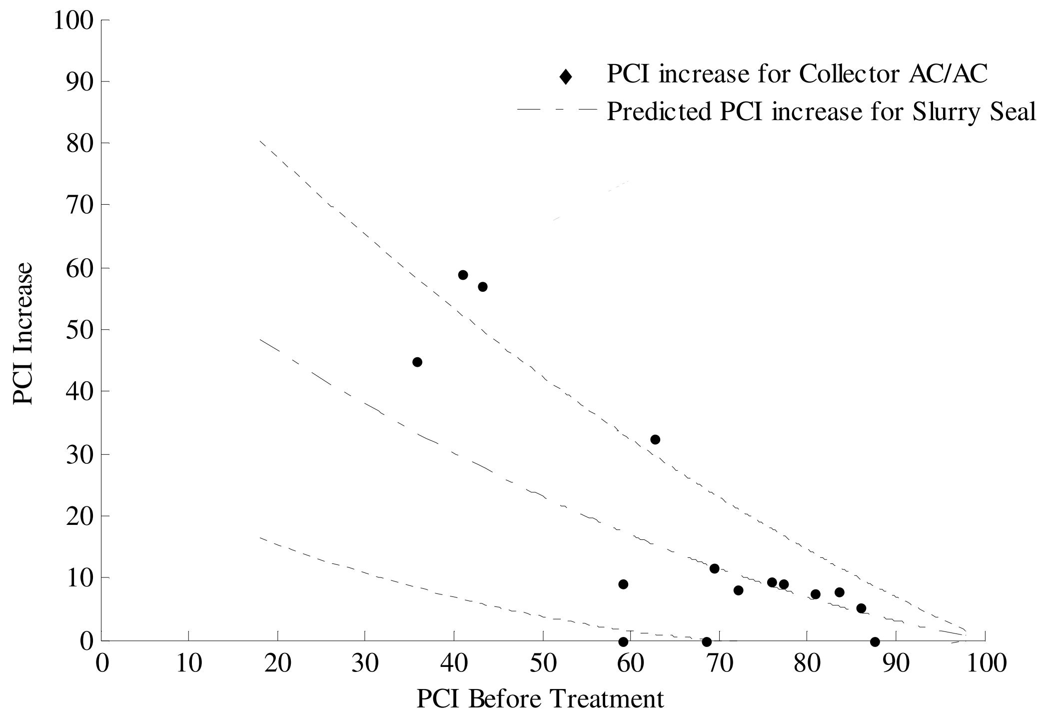

Figure 14: Slurry seal collector AC/AC family and mean and prediction interval for slurry seal family for PCI increase

Figure 15 shows the results of the weighted regression analyses to determine PCI increase for slurry seal treatment for functional class residential and surface type AC/AC. Table 9 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 9 also shows the R^2, *F*-

statistics and *t*-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance ($\alpha = 0.1$), the obtained F_0 value for the developed model is 185.670 > $f_{0.1,1,317} = 2.75$ [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 211.453> $f_{0.1,2,316} = 2.35$ [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for the 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerable lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The significance of the coefficients for the second order equation is shown by the computed *t*-statistics which are greater than $t_{0.05,316} = 1.658$ [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the coefficients in the second order equation are significant. Therefore, the data for slurry seal residential AC/AC is fitted using a 2nd order polynomial equation shown in Equation (18).

$$Y = 0.009x^2 - 1.891x + 95.222 \tag{18}$$

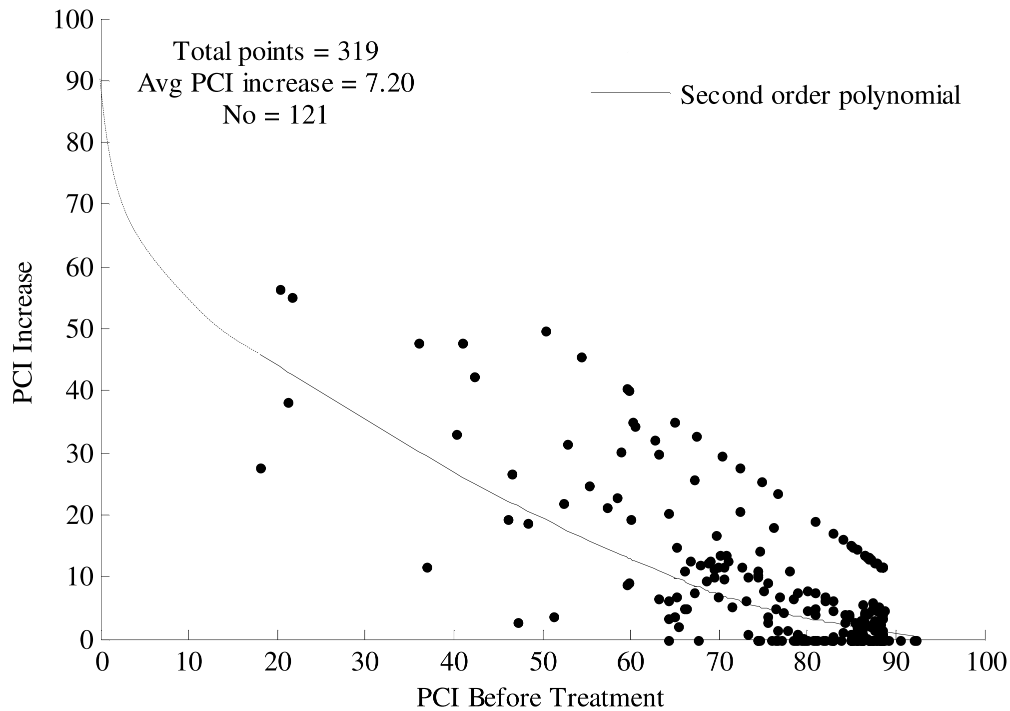

Figure 15: PCI increase equation for slurry seal treatments with functional class residential and surface type AC/AC

Table 9: Coefficients of regression for slurry seal treatments with functional class residential and surface type AC/AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	42.659	-0.453	-	0.359	185.670>2.75	0.369
t-statistics	|8.891|>1.658	|-8.096|>1.658	-			
2nd order	95.222	-1.891	9.592E-03	0.355	211.453>2.35	0.572
t-statistics	|5.286|>1.658	|-3.949|>1.658	|3.024|>1.658			

Figure 16 shows the results of weighted regression analyses conducted for slurry seal residential surface type AC/AC without considering the data sets with 0 PCI increase values. The average PCI increase is about 12. Table 10 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 122.069 > $f_{0.1,1,196}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 108.605> $f_{0.1,2,195}$ = 2.35 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The significance of the coefficients in the second order equation are shown by the computed *t*-statistics which are greater than $t_{0.05,195}$ = 1.658 [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the coefficients in the second order equation are significant. Therefore, the data for slurry seal residential AC/AC excluding 0 PCI increase values is fitted using a 2nd order polynomial equation shown in Equation (19).

$$Y = 0.006x^2 - 1.417x + 79.199 \tag{19}$$

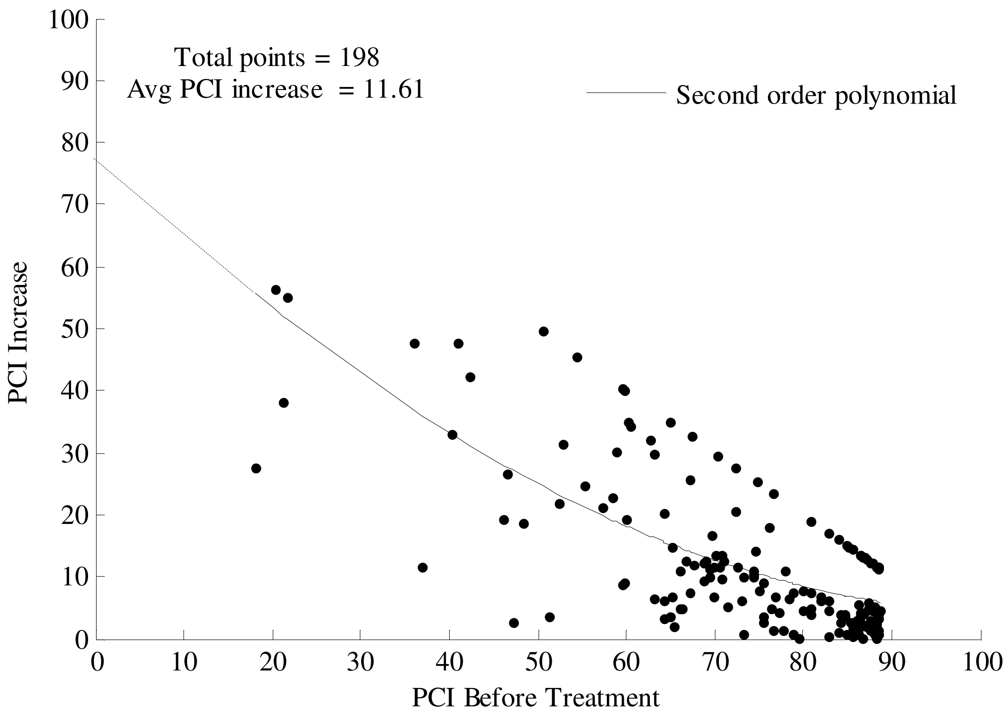

Figure 16: PCI increase equation for slurry seal treatments with functional class residential and surface type AC/AC excluding 0 PCI increase values

Table 10: Coefficients of regression for slurry seal treatments with functional class residential and surface type AC/AC excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	44.589	-0.439	-	0.358	122.069>2.75	0.384
t-statistics	|8.490|>1.658	|-7.128|>1.658	-			
2nd order	79.199	-1.417	6.672E-03	0.356	108.605>2.35	0.527
t-statistics	|4.086|>1.658	|-2.669|>1.658	|1.854|>1.658			

Figure 17 shows the comparison of the two equations for residential AC/AC with and without considering the 0 PCI increase values. The solid lines in the figure represent the mean and 90% prediction interval for the model developed considering the 0 PCI increase values for slurry seal residential AC/AC family. The dotted lines in the figure represent the mean and 90% prediction interval for the slurry seal residential AC/AC model developed by excluding the 0 PCI increase values. In the figure it is observed that the prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar and the effect of 0 PCI increase values on the developed equation can be neglected. Hence, the Equation (18) developed for slurry seal residential AC/AC can be used to show the trend in PCI increase for slurry seal residential AC/AC family.

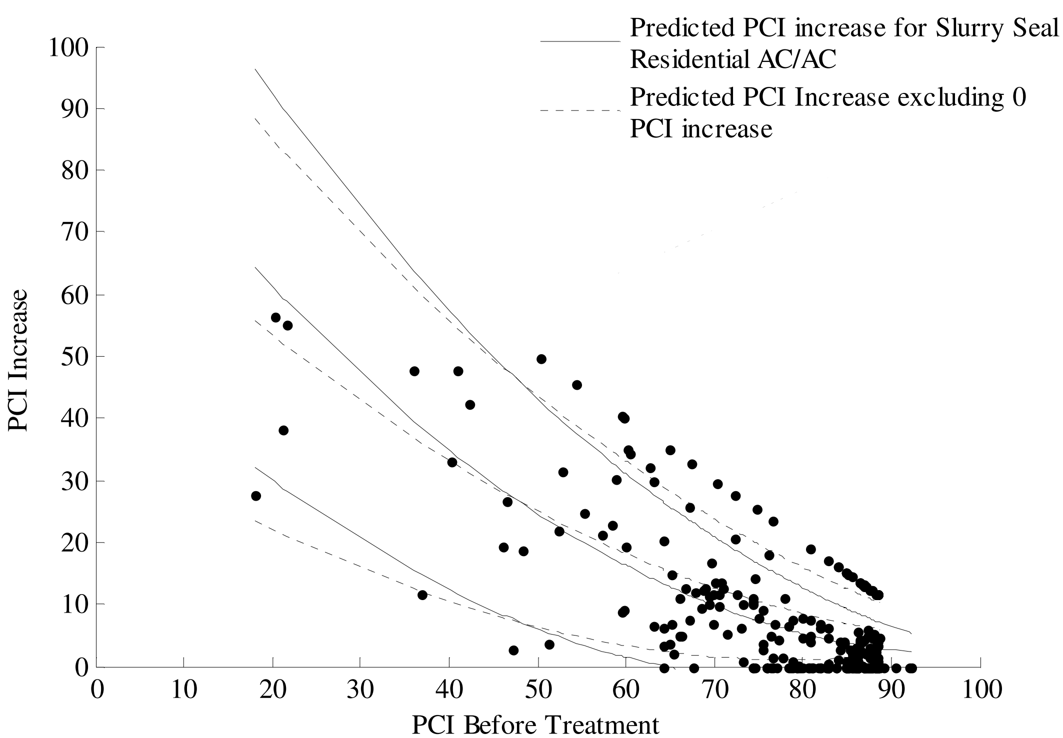

Figure 17: Mean and prediction interval for slurry seal residential AC/AC family with and without data sets with PCI increase as 0

For the slurry seal group, the Equation (12) developed for slurry seal should be used in PMS to show the PCI increase trends for arterial AC/AC and collector AC/AC whereas Equation (14) and Equation (15) should be used to show the PCI increase trends for arterial AC and collector AC respectively. The Equation (16) and Equation (18) should be used to show the PCI increase trends for residential AC and AC/AC family respectively. Figure 18 gives the summary of the equations that can be used to show the PCI increase trends for different functional class and surface type combinations.

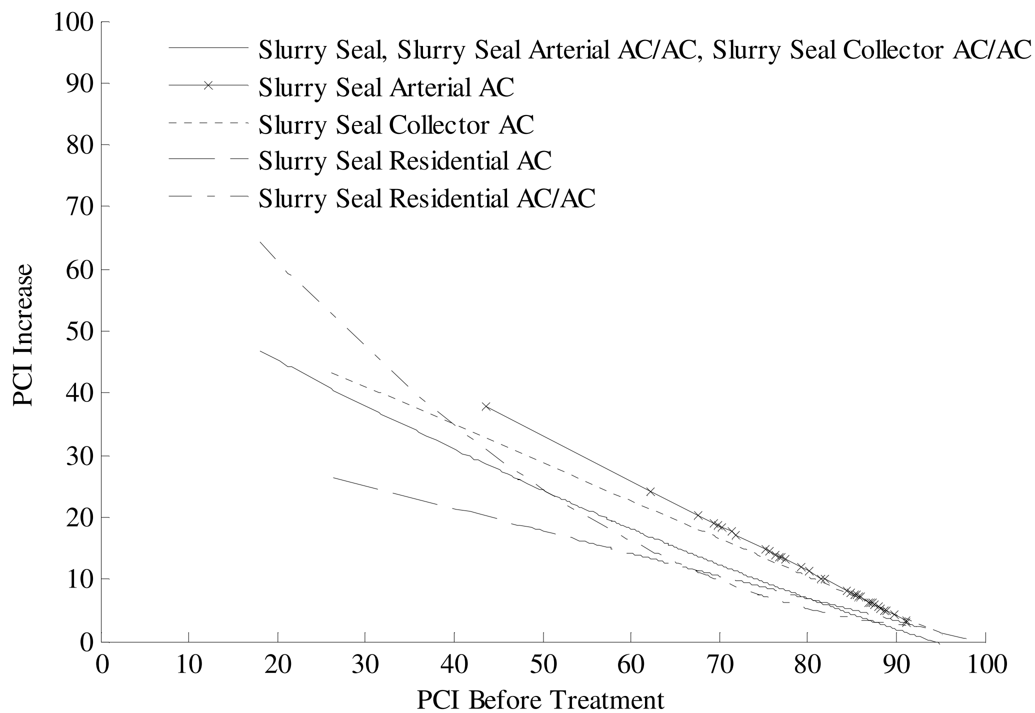

Figure 18: Summary of equations found for PCI increase for slurry seal treatments

2.4.2 Cape Seal

Cape seal treatments are generally applied when the pavement deterioration is greater than what a slurry seal is designed to correct [4]. Figure 19 shows the results of weighted regression analyses to determine PCI increase for cape seal treatments. In this data set the PCI increase values for all the sections treated with cape seals are plotted with respect to PCI before treatment. The average PCI increase with a cape seal treatment is about 12. Table 11 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 11 also shows the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 302.444 > $f_{0.1,1,762}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 285.293> $f_{0.1,2,761}$ = 2.35 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The computed *t*-statistics of the coefficients for the second order equation are greater than $t_{0.05,761}$ = 1.657, showing the significance of the coefficients in the second order equation for cape seal treatments [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the second order equation is significant. Hence, the data for cape seal treatments is fitted using a 2nd order polynomial shown in Equation (20).

$$Y = 0.004x^2 - 1.109x + 63.485 \tag{20}$$

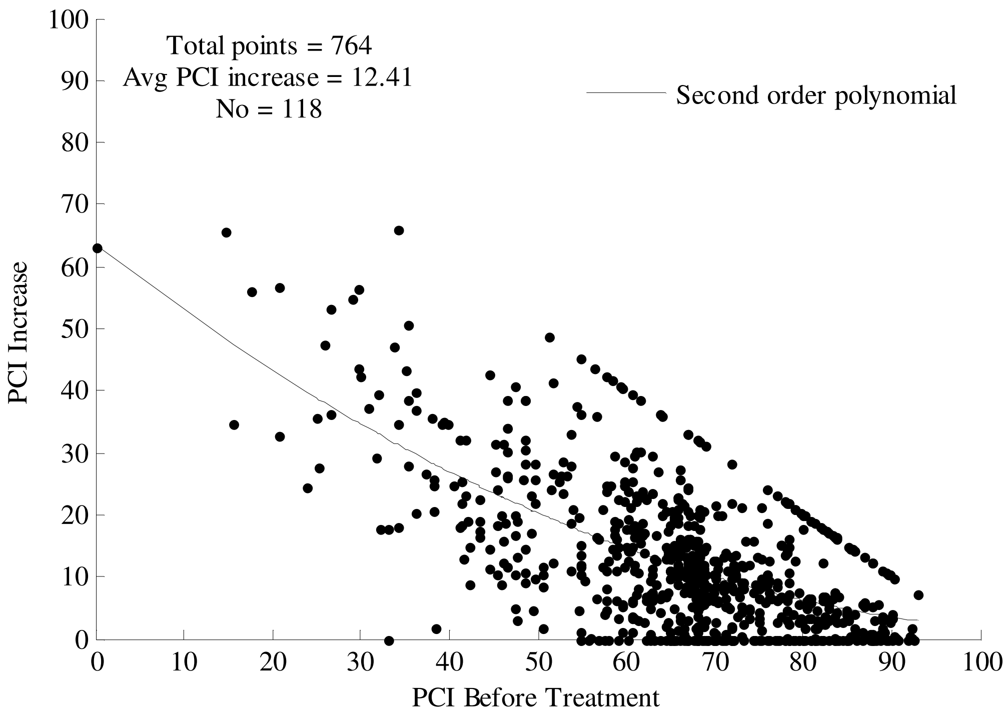

Figure 19: PCI increase equation for cape seal treatments

Table 11: Coefficients of regression for cape seal maintenance treatments

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order t-statistics	38.537 |21.991|>1.657	-0.396 |-18.095|>1.657	- -	0.287	302.444>2.75	0.284
2nd order t-statistics	63.485 |9.659|>1.657	-1.109 |-6.076|>1.657	4.932E-03 |3.935|>1.657	0.285	285.293>2.35	0.429

Figure 20 shows the results of regression analyses conducted without considering the 0 PCI increase values. The average PCI increase on excluding 0 PCI increase values is about 15. Table 12 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 122.069 > $f_{0.1,1,644}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 108.605> $f_{0.1,2,643}$ = 2.35 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The computed *t*-statistics for the coefficients in the second order equation are greater than $t_{0.05,643}$ = 1.657, showing the significance of the coefficients in the second order equation for cape seal treatments [17]. Hence, we can reject the null hypothesis (H_o) of the *t*-statistics and conclude that the coefficients in the second order equation are significant. Therefore, the data for cape seal excluding 0 PCI increase values is fitted using a 2nd order polynomial shown in Equation (21).

$$Y = 0.004x^2 - 1.109x + 63.485 \tag{21}$$

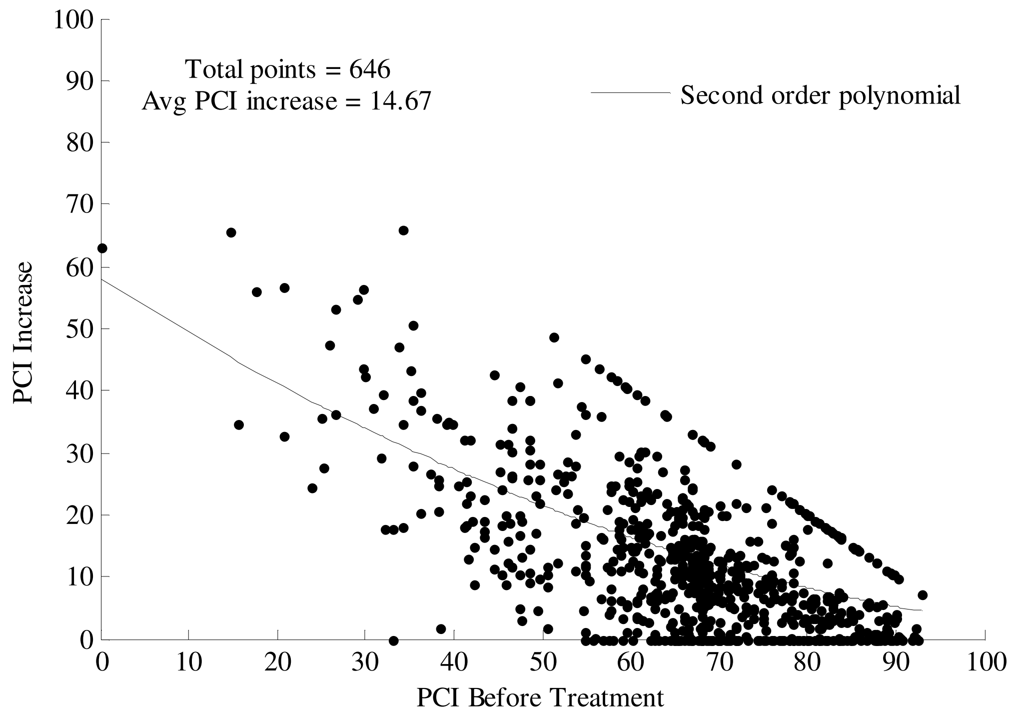

Figure 20: PCI increase equation for cape seal treatments excluding points corresponding to 0 PCI increase

Table 12: Coefficients of regression for cape seal maintenance treatments excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	44.589	-0.439	-	0.358	122.069>2.75	0.384
t-statistics	|8.490|>1.657	|-7.128|>1.657	-			
2nd order	79.199	-1.417	6.672E-03	0.356	108.605>2.35	0.527
t-statistics	|4.086|>1.657	|-2.669|>1.657	|1.854|>1.657			

Figure 21 in shows the comparison of two models. The solid lines in the figure represent the mean and 90% prediction interval for the model developed for cape seal considering the 0 PCI increase values. The dotted lines in the figure represent the mean and 90% prediction interval for the model developed for cape seal excluding the 0 PCI increase values. In the figure it is observed that the prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar, and the effect of 0 PCI increase values on the developed equation can be neglected. Hence, Equation (20) developed for cape seal can be used to show the PCI increase trend for cape seal family. Also, 90% of the data in Figure 19 has PCI before treatment values ranging from 40 to 90, which is the typical range of PCI values at which cape seal treatments are normally applied.

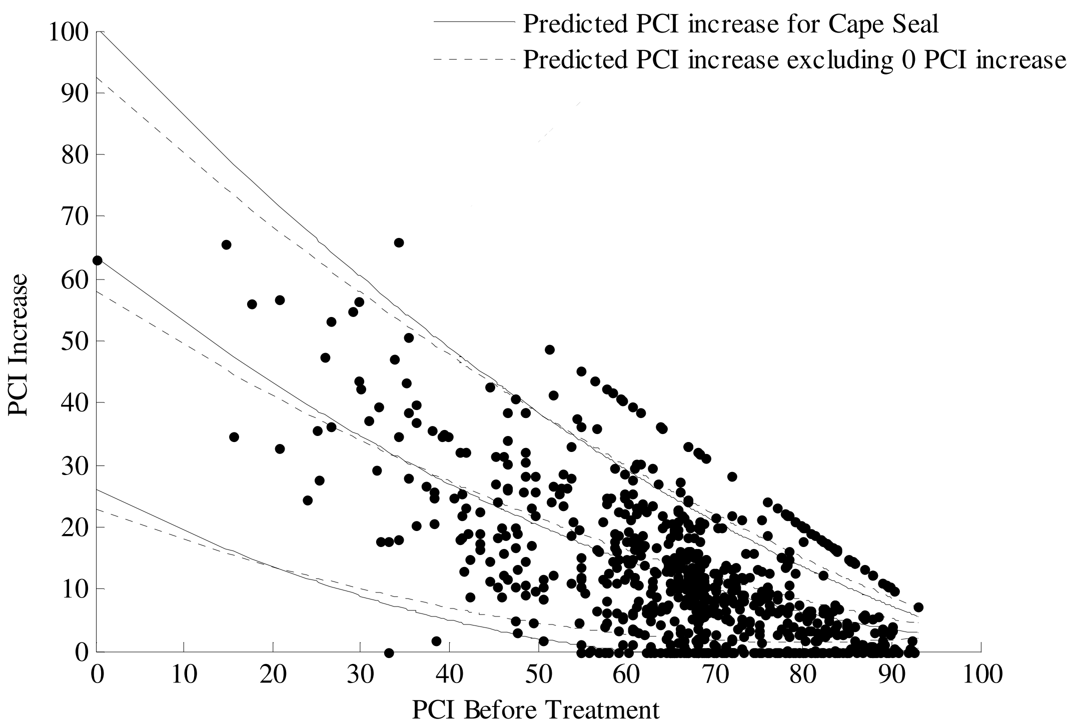

Figure 21: Mean and prediction interval for cape seal family with and without data sets with PCI increase as 0

To see the effect of functional class and surface type, the cape seal family can be further grouped in functional class and surface type families like collector AC, collector AC/AC, residential AC and residential AC/AC. Since no data is available for functional classification arterial, the data is not grouped in this class. Table 13 gives the number of data sets used in analysis for each functional class surface type combination and the numbers of data sets with PCI increase value as 0.

Table 13: Number of data sets for PCI increase and 0 PCI increase for all functional class surface type combination for cape seal

Functional Class - Surface Type	PCI Increase Data sets	Data sets with PCI Increase as 0
Arterial AC	0	0
Arterial AC/AC	4	1
Collector AC	111	10
Collector AC/AC	50	22
Residential AC	548	70
Residential AC/AC	51	15
Total	764	118

Figure 22 shows the results of weighted regression analyses for functional class collector and surface type AC. The average PCI increase for this family is about 11. Table 14 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 14 also shows the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 91.237> $f_{0.1,1,109}$ = 2.79 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 60.538 > $f_{0.1,2,108}$ = 2.39 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. However, the t-statistics show that the first and the second order coefficients in the second order polynomial equation are not greater than $t_{0.05,108} = 1.661$ [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics and conclude that the coefficients in the second order polynomial equation are not significant. Therefore, the data for cape seal collector AC is fitted using a 1st order polynomial shown in Equation (22).

$$Y = -0.460x + 45.861 \tag{22}$$

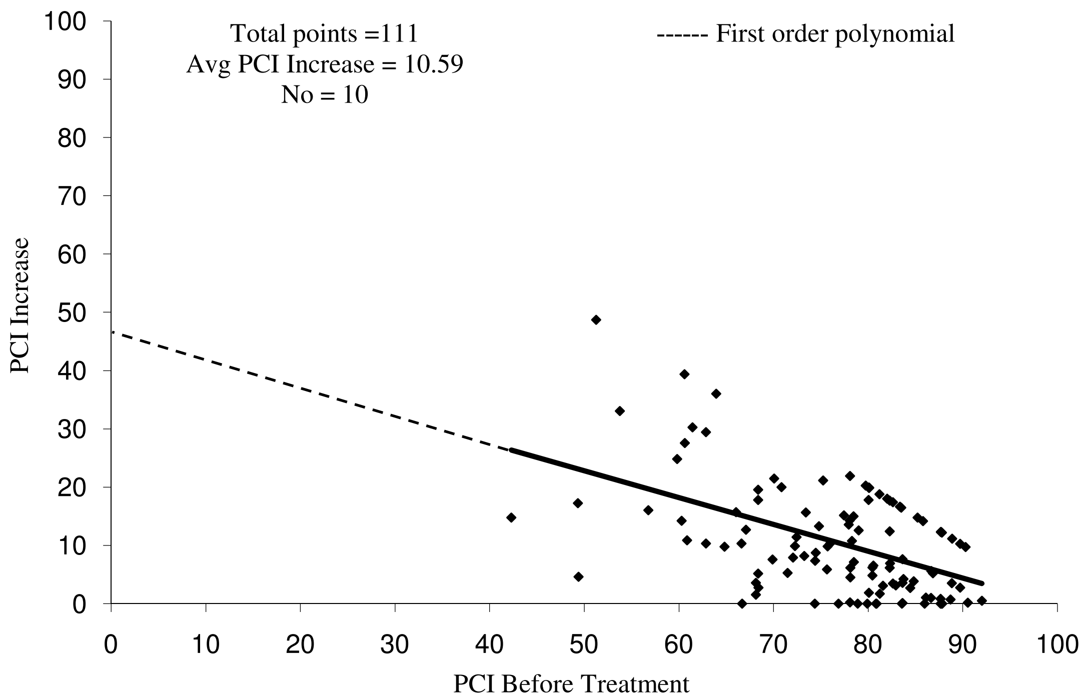

Figure 22: PCI increase equation for cape seal treatments with functional class collector and surface type AC

Table 14: Coefficients of regression for cape seal treatments with functional class collector and surface type AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order t-statistics	45.861 |10.219|>1.661	-0.460 |-8.136|>1.661	- -	0.341	91.237>2.79	0.255
2nd order t-statistics	44.181 |4.735|>1.661	-0.412 |-1.342|<1.661	3.080E-03 |0.927|<1.661	0.344	60.583>2.39	0.255

Since the number of data sets with 0 PCI increase value is small, the analysis excluding 0 PCI increase data sets was not conducted. The Equation (22) can be used to show the PCI increase trend for cape seal collector AC family.

Figure 23 shows the results of weighted regression analyses for functional class residential and surface type AC. The average PCI increase for this group is 14. Table 15 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 15 also shows the R^2, F-statistics and t-statistics values used for statistical analysis of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 155.742 > $f_{0.1,1,546}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 193.977 > $f_{0.1,2,545}$ = 2.39 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that the addition of the second order term improves the model. The computed t-statistics for the coefficients of the second order equation are greater than $t_{0.05,545}$ = 1.657, showing the significance of the coefficients in the second order polynomial equation [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics for the second order equation and conclude that the equation is significant. Therefore, the data for cape seal residential AC is fitted using a 2nd order polynomial shown in Equation (23).

$$Y = 0.007x^2 - 1.369x + 70.611 \tag{23}$$

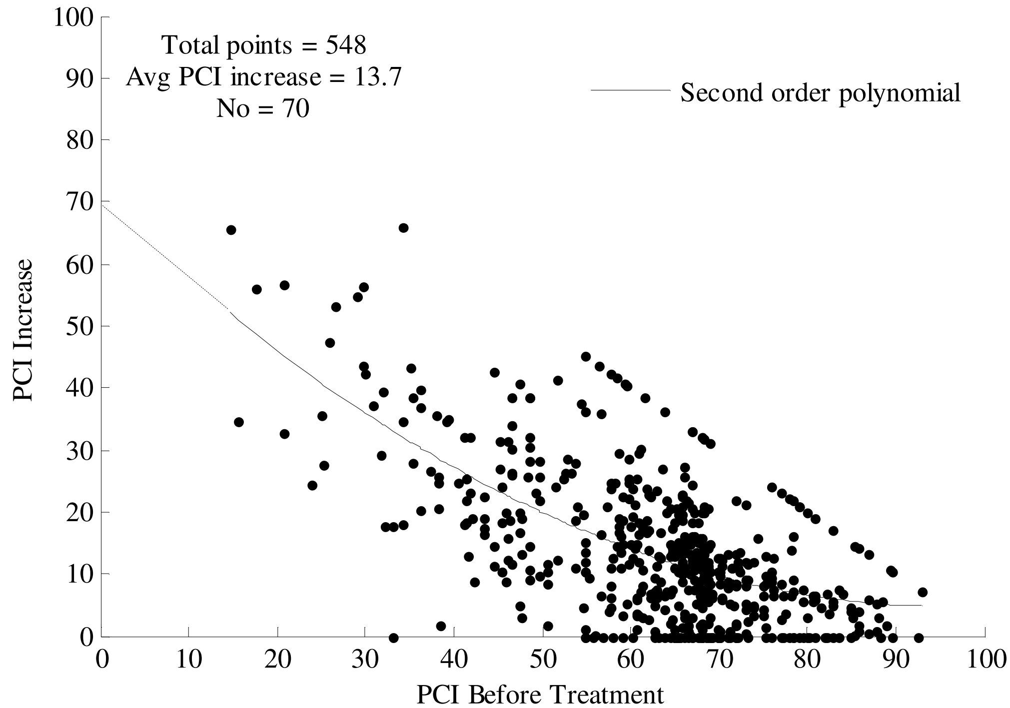

Figure 23: PCI increase equation for cape seal treatments with functional class residential and surface type AC

Table 15: Coefficients of regression for cape seal maintenance treatments with functional class residential and surface type AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	36.794	-0.371	-	0.268	155.742>2.75	0.222
t-statistics	|18.465|>1.657	|-14.100|>1.657	-			
2nd order	70.611	-1.369	7.118E-03	0.262	193.977>2.39	0.416
t-statistics	|10.141|>1.657	|-6.878|>1.657	|5.059|>1.657			

Figure 24 shows the results of weighted regression analyses conducted for cape seal residential and surface type AC without considering the data sets with 0 PCI increase values. The average PCI increase is about 12. Table 16 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical analysis of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 148.947 > $f_{0.1,1,476}$ = 2.75 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 170.029 > $f_{0.1,2,475}$ = 2.35 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that addition of the second order term improves the model. The computed t-statistics for the coefficients of the second order polynomial equation are greater than $t_{0.05,475}$ = 1.658, showing the significance of the coefficients in the second order equation [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the second order equation is significant. Therefore, the data for cape seal residential AC excluding 0 PCI increase values is fitted using a 2nd order polynomial shown in Equation (24).

$$Y = 0.006x^2 - 1.231x + 66.975 \tag{24}$$

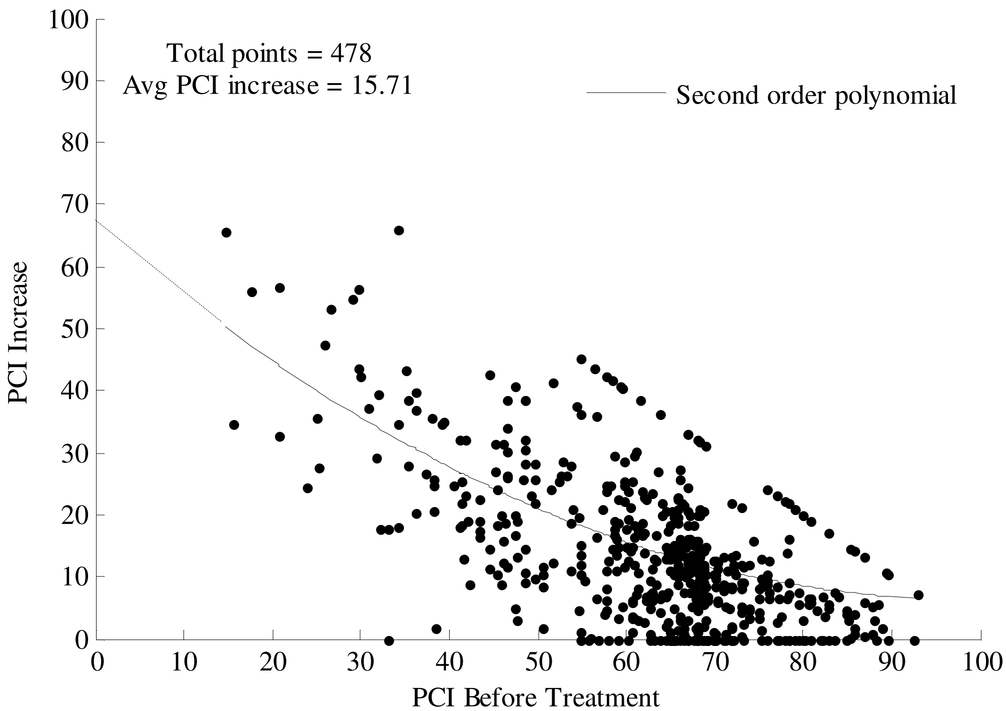

Figure 24: PCI increase equation for cape seal treatments with functional class residential and surface type AC excluding points corresponding to 0 PCI increase

Table 16: Coefficients of regression for cape seal maintenance treatments with functional class residential and surface type AC excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	38.122	-0.365	-	0.244	148.947>2.75	0.238
t-statistics	|19.626|>1.658	|-14.087|>1.658	-			
2nd order	66.975	-1.231	6.255E-03	0.239	170.029>2.35	0.417
t-statistics	|10.096|>1.658	|-6.399|>1.658	|4.540|>1.658			

Figure 25 shows the comparison of the two equations for residential AC with and without considering the 0 PCI increase values. The solid lines in the figure represent the mean and 90% prediction interval for the model developed considering the 0 PCI increase values for cape seal residential AC family. The dotted lines in the figure represent the mean and 90% prediction interval for the cape seal residential AC model developed by excluding the 0 PCI increase values. In the figure it is observed that the prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar and the effect of 0 PCI increase values on the developed equation can be neglected. Hence, the Equation (23) developed for cape seal residential AC can be used to show the PCI increase trend for cape seal residential AC family.

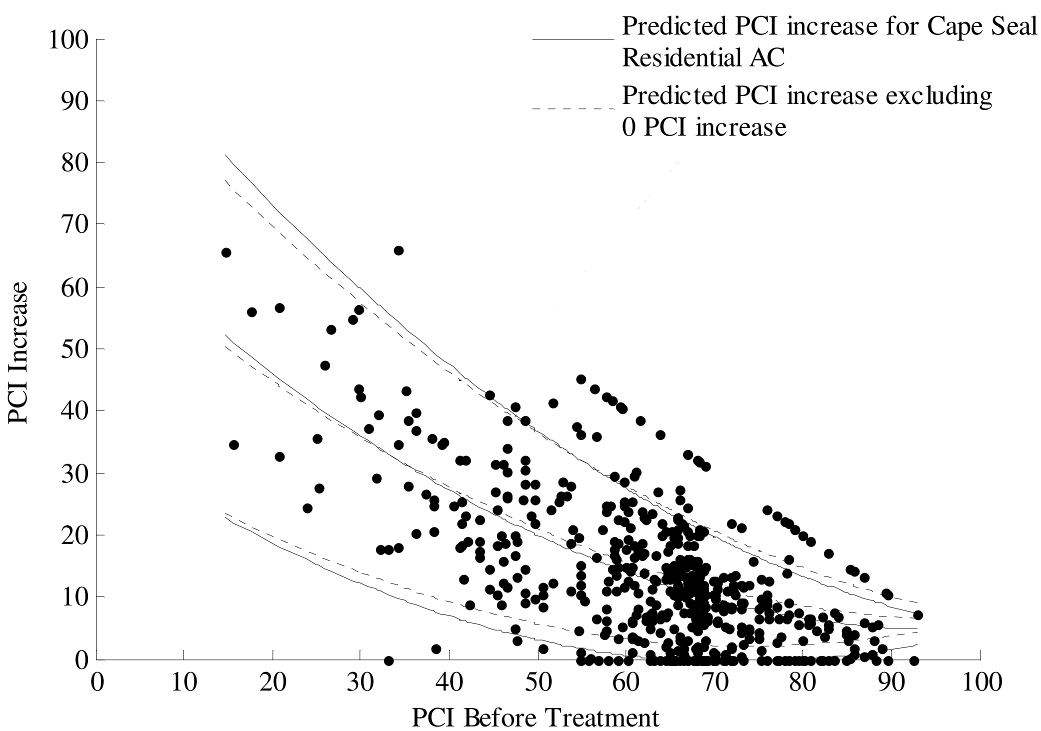

Figure 25: Mean and prediction interval for cape seal residential AC family with and without data sets with PCI increase as 0

Figure 26 shows the result of weighted regression analyses for functional class collector and surface type AC/AC. The average PCI increase for this group is 3.38 which is very small compared to other cape seal families. Table 17 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 17 also shows the R^2, F-statistics and t-statistics values used for statistical analysis of the developed models. For the 1st order polynomial equation, with the desired level of significance ($\alpha = 0.1$), the obtained F_0 value for the developed model is $4.033 > f_{0.1,1,48} = 2.84$ [17]. For the 2nd order polynomial equation, the obtained F_0 value for the developed model is $1.258 < f_{0.1,2,47} = 2.35$ [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st order polynomial equation but we accept the null hypothesis for the second order polynomial equation. However the R^2 value for the 1st order polynomial equation is 0.053 which is very low. Therefore the prediction capability of the first order equation is so low that it cannot be considered adequate to show the PCI increase trend for cape seal collector AC/AC family.

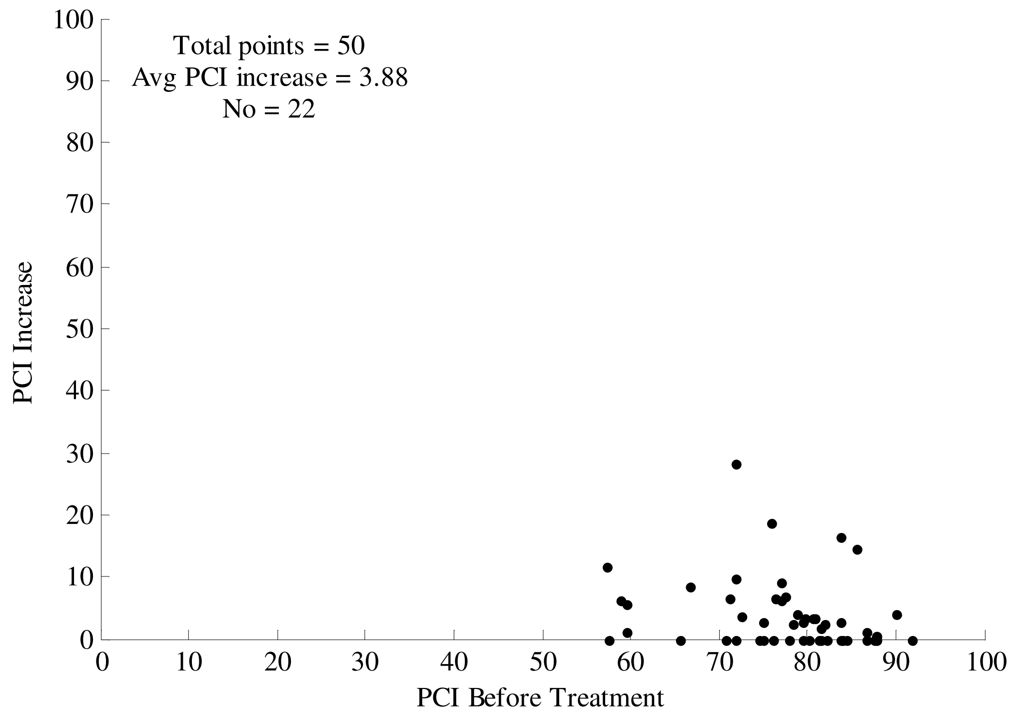

Figure 26: PCI increase equation for cape seal treatments with functional class collector and surface type AC/AC

Table 17: Coefficients of regression for cape seal treatments with functional class collector and surface type AC/AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order t-statistics	18.797 $\lvert 2.235 \rvert > 1.679$	-0.192 $\lvert -1.899 \rvert > 1.679$	- -	0.262	4.033>2.84	0.053
2nd order t-statistics	-10.830 $\lvert -0.185 \rvert < 1.679$	0.563 $\lvert 0.380 \rvert < 1.679$	-4.768E-03 $\lvert -0.511 \rvert < 1.679$	0.264	1.258<2.35	0.040

Figure 27 shows the results of weighted regression analyses conducted for cape seal collector and surface type AC/AC without considering the data sets with 0 PCI increase values. The average PCI increase for this group is 6.68 which is very small compared to other cape seal families. Table 18 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical analysis of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 2.423 < $f_{0.1,1,26}$ = 2.91 [17]. For the 2nd order polynomial equation, the obtained F_0 value for the developed model is 0.749< $f_{0.1,2,25}$ = 2.53 [17]. Thus, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI increase and PCI before treatment for this family. Hence, an equation cannot be formed based on the available data, to show the PCI increase trend for cape seal collector AC/AC family.

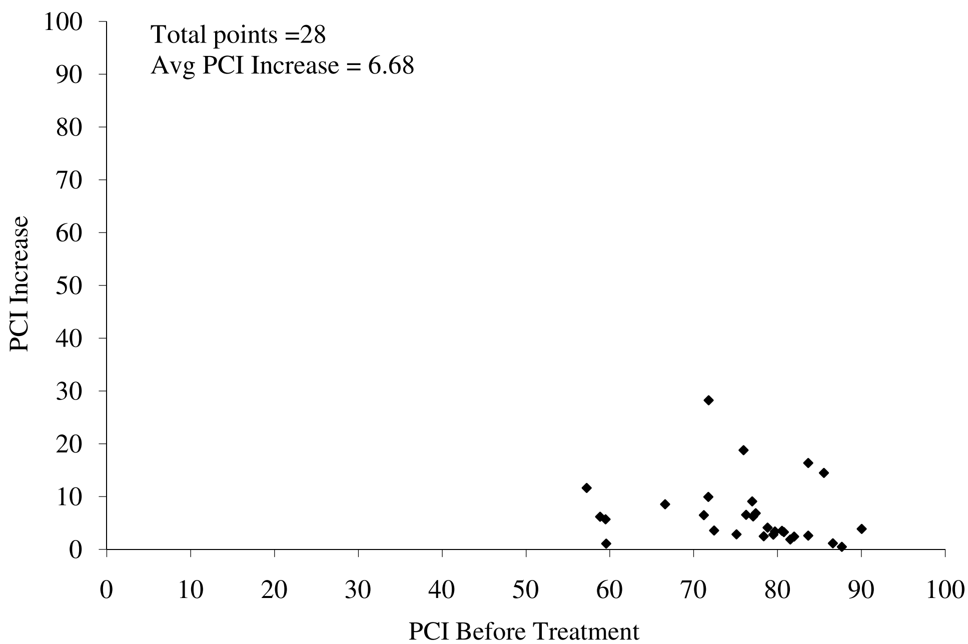

Figure 27: PCI increase equation for cape seal treatments with functional class collector and surface type AC/AC excluding points corresponding to 0 PCI increase

Table 18: Coefficients of regression for cape seal treatments with functional class collector and surface type AC/AC excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	22.734	-0.209	-	0.286	2.423<2.91	0.082
t-statistics	|1.811|>1.708	|-1.364|<1.708	-			
2nd order	-25.535	1.049	-8.113E-3	0.29	0.749<2.53	0.054
t-statistics	|-0.298|<1.708	|0.474|<1.708	|-0.569|<1.708			

Figure 28 shows the result of weighted regression analyses for cape seal treatments with functional class residential and surface type AC/AC. The average PCI increase for this group is about 7.89. Table 19 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 19 also shows the R^2, F-statistics and t-statistics values used for statistical analysis of the developed models. For the 1st order polynomial equation, with the desired level of significance ($\alpha = 0.1$), the obtained F_0 value for the developed model is 44.936> $f_{0.1,1,49}$ = 2.81 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 36.988 > $f_{0.1,2,48}$ = 2.40 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. However, the t-statistics for the second order coefficient of the second order polynomial equation is not greater than $t_{0.05,48}$ = 1.679 [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics for the second order coefficient of the second order polynomial equation and conclude that the second order equation is not significant. Therefore, the data for cape seal residential AC/AC is fitted using a 1st order polynomial equation shown in Equation (25).

$$Y = -0.441x + 40.5 \tag{25}$$

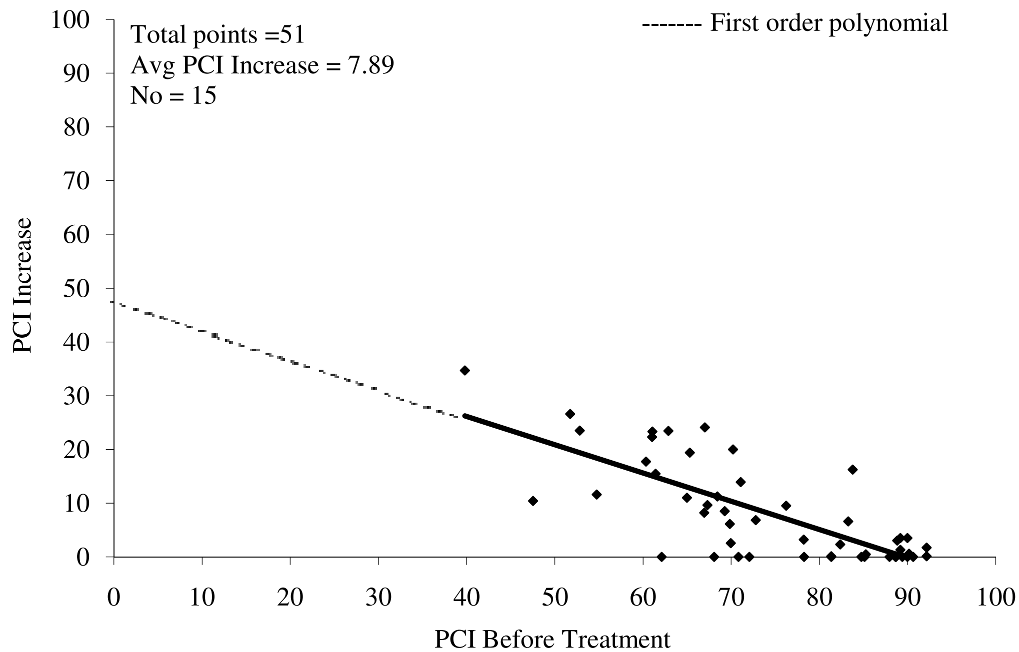

Figure 28: PCI increase equation for cape seal treatments with functional class residential and surface type AC/AC

Table 19: Coefficients of regression for cape seal treatments with functional class residential and surface type AC/AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	40.500	-0.441	-	0.225	44.936>2.81	0.478
t-statistics	|7.434|>1.679	|-6.991|>1.679	-			
2nd order	89.554	-1.746	8.465E-03	0.221	36.988>2.40	0.606
t-statistics	|2.865|>1.679	|-2.125|>1.679	|1.593|<1.679			

Figure 29 shows the results of weighted regression analyses conducted for cape seal residential and surface type AC/AC family without considering the data sets with 0 PCI increase. The average PCI increase is about 11. Table 20 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 49.052 > $f_{0.1,1,34}$ = 2.85 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 27.694 > $f_{0.1,2,33}$ = 2.46 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. However, the t-statistics for the first and the second order coefficients for the second order equation are not significant i.e. the computed t-statistics are not greater than $t_{0.05,33}$ = 1.693 [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics for the second order polynomial equation and conclude that the second order equation is not significant. Therefore, the data for cape seal residential AC/AC excluding 0 PCI increase values is fitted using a 1st order polynomial shown in Equation (26).

$$Y = -0.497x + 46.655 \tag{26}$$

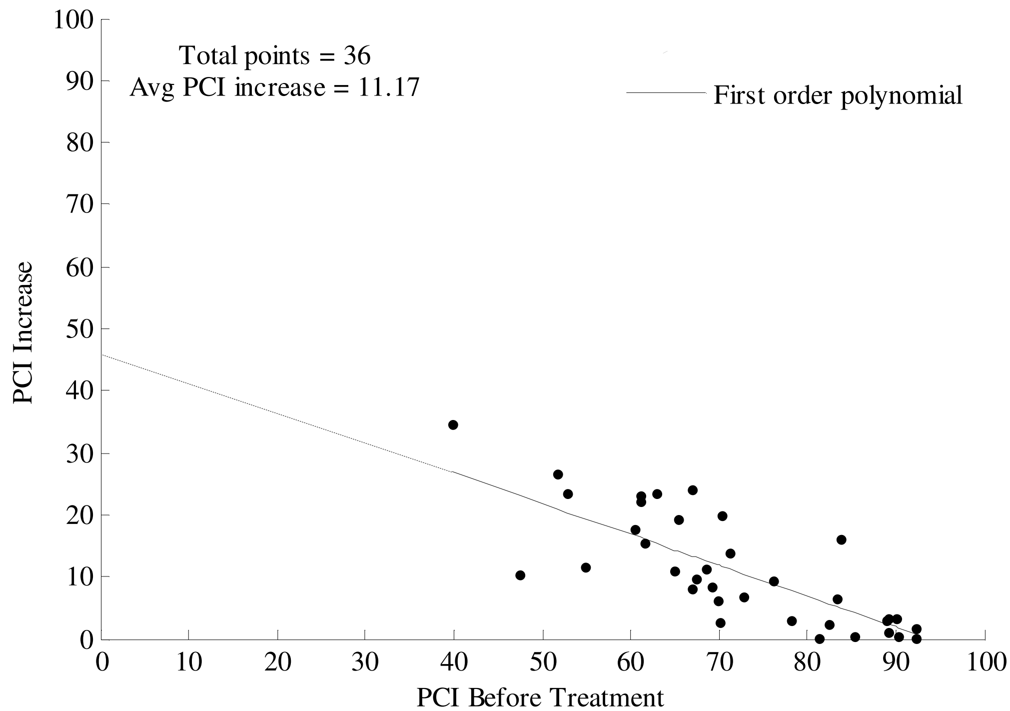

Figure 29: PCI increase equation for cape seal treatments with functional class residential and surface type AC/AC excluding 0 PCI increase

Table 20: Coefficients of regression for cape seal treatments with functional class residential and surface type AC/AC excluding points corresponding to 0 PCI increase

Type of Polynomial	Intercept	x	x^2	S	F-statistics	R^2
1st order	46.655	-0.497	-	0.209	49.052>2.85	0.591
t-statistics	|8.449|>1.693	|-7.718|>1.693	-			
2nd order	61.484	-0.895	2.600E-03	0.211	27.694>2.46	0.627
t-statistics	|1.940|>1.693	|-1.065|<1.693	|0.475|<1.693			

Figure 30 shows the comparison of the two equations for residential AC/AC with and without considering the 0 PCI increase values. The solid lines in the figure represent the mean and 90% prediction interval for the model developed considering the 0 PCI increase values for cape seal residential AC/AC family. The dotted lines in the figure represent the mean and 90% prediction interval for the cape seal residential AC/AC model developed by excluding the 0 PCI increase values. In the figure it is observed that the prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar and the effect of 0 PCI increase values on the developed equation can be neglected. Therefore, the Equation (25) can be used to show the trend in PCI increase values for cape seal residential AC/AC family.

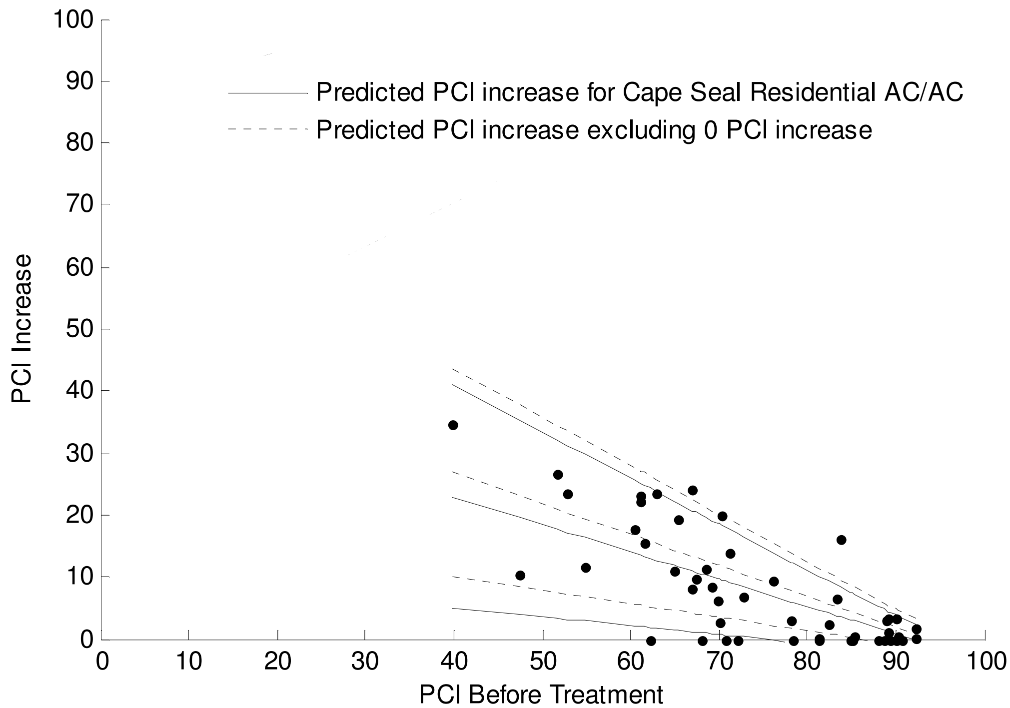

Figure 30: Mean and prediction interval for cape seal residential AC/AC family with and without data sets with PCI increase as 0

For the cape seal group, the Equation (20) developed for cape seal should be used in PMS to show the PCI increase trends for cape seal family. The Equation (22) and Equation (23) should be used in PMS to show the PCI increase trends for collector AC and residential AC family respectively. The Equation (25) should be used in PMS to show the PCI increase trends for residential AC/AC family. Since no data is available for functional class arterial, equations developed above cannot be used to show the PCI increase trends for arterial AC and arterial AC/AC families. More data is needed to determine the equations for these families. Also an equation cannot be formed for collector AC/AC based on the available data. Figure 31 gives the summary of equations that can be used to show the PCI increase trends for different functional class and surface type combinations.

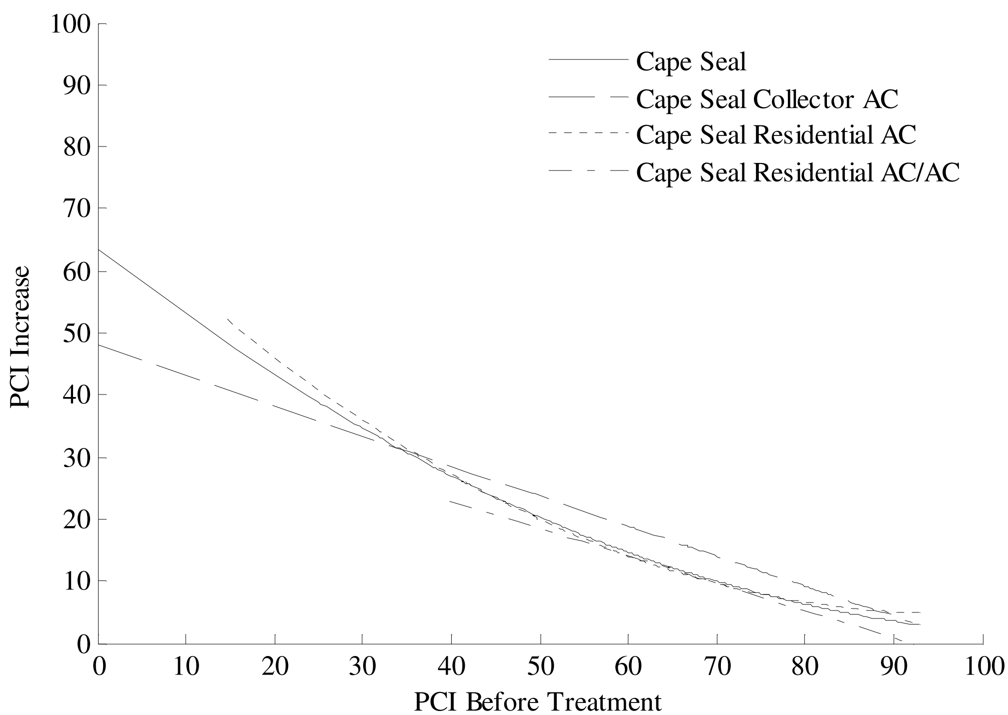

Figure 31: Summary of equations found for PCI increase for cape seal treatments

2.4.3 Crack Seal

Crack seal treatments are generally applied to the pavements to seal cracks. If the cracks are not maintained, the cracks can ravel, increase in size and accelerate deterioration of the pavement. Figure 32 shows the results of weighted regression analyses conducted to determine a PCI increase equation for crack seal type of treatment. The average PCI increase with a crack seal treatment is about 3 which is very low compared to the PCI increase value for slurry seal and cape seal, but that is expected. Table 21 gives the regression coefficients obtained for the 1st and 2nd order equations fitted to the data as obtained from Minitab. Table 21 also shows the R^2, F-statistics and t-statistics values used for statistical validation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 15.828 > $f_{0.1,1,100}$ = 2.79 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 19.986> $f_{0.1,2,99}$ = 2.39 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial. The R^2 value for the 1st order polynomial equation is considerably lower than for the 2nd order polynomial equation which shows that addition of the second order term improves the model. The computed t-statistics for the coefficients in the second order polynomial equation are greater than $t_{0.05,99}$ = 1.663 [17]. Hence, we can reject the null hypothesis (H_o) of the t-statistics and conclude that the second order equation is significant. Therefore, the data for crack seal is fitted using a 2nd order polynomial equation shown in Equation (27).

$$Y = 0.003x^2 - 0.710x + 37.688 \tag{27}$$

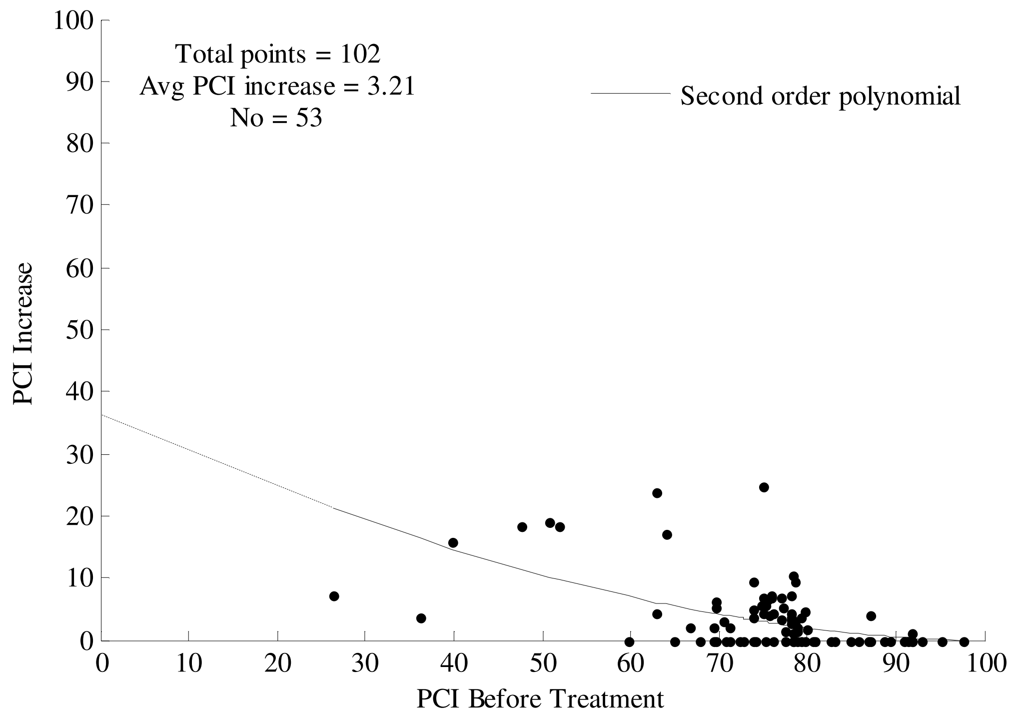

Figure 32: PCI increase equation for crack seal treatments

Table 21: Coefficients of regression for crack seal treatments

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	14.856	-0.157	-	0.162	15.828>2.79	0.137
t-statistics	|6.701|>1.663	|-6.372|>1.663	-			
2nd order	37.688	-0.710	3.297E-03	0.159	19.986>2.39	0.288
t-statistics	|3.083|>1.663	|-2.428|>1.663	|1.898|>1.663			

Figure 33 shows the results of weighted regression analyses conducted for crack seal family without considering the data sets with 0 PCI increase. The average PCI increase is about 6.68. Table 22 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the developed models. For the 1st order polynomial equation, with the desired level of significance (α = 0.1), the obtained F_0 value for the developed model is 19.318 > $f_{0.1,1,47}$ = 2.81 [17]. Similarly for the 2nd order polynomial equation, the obtained F_0 value for the developed model is 7.239> $f_{0.1,2,46}$= 2.40 [17]. Thus, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI increase and PCI before treatment for 1st and 2nd order polynomial equations. However, the t-statistics of the coefficients for the second order polynomial equation are not significant i.e. the computed t-statistics are not greater than $t_{0.05,46}$ = 1.680 [17]. Hence, we cannot reject the null hypothesis (H_o) of the t-statistics and conclude that the second order equation is not significant. Therefore, the data for crack seal excluding 0 PCI increase values is fitted using a 1st order polynomial shown in Equation (28).

$$Y = -0.270x + 26.077 \tag{28}$$

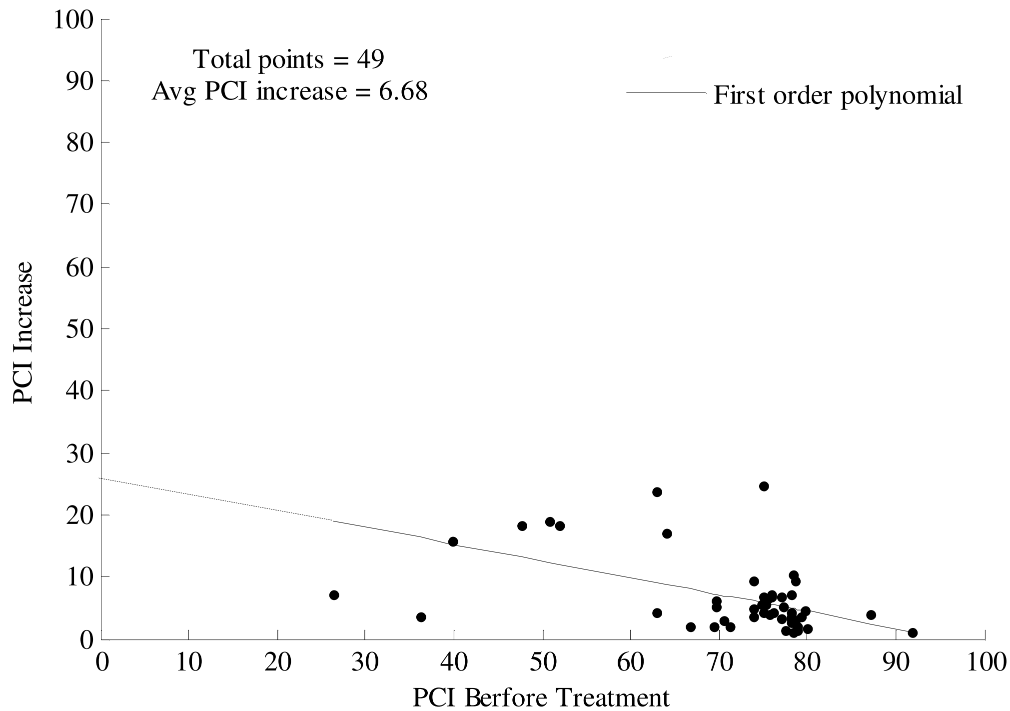

Figure 33: PCI increase equation for crack seal treatments excluding 0 PCI increase values

Table 22: Coefficients of regression for crack seal treatments excluding 0 PCI increase values

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	26.077	-0.270	-	0.172	19.318>2.81	0.291
t-statistics	|4.981|>1.680	|-4.089|>1.680	-			
2nd order	19.857	-0.099	-1.164E-03	0.173	7.239>2.40	0.239
t-statistics	|1.143|<1.680	|-0.214|<1.680	|-0.376|<1.680			

Figure 34 shows the comparison of the two equations for crack seal with and without considering the 0 PCI increase values. The solid lines in the figure represent the mean and 90% prediction interval for the model developed considering the 0 PCI increase values for crack seal family. The dotted lines in the figure represent the mean and 90% prediction interval for the crack seal model developed by excluding the 0 PCI increase values. In the figure it is observed that the prediction intervals appear not to differ very much. The two models developed with and without considering the 0 PCI increase values are similar and the effect of 0 PCI increase values on the developed equation can be neglected. The Equation (27) developed for crack seal should be used to show the PCI increase trends for crack seal family. Also, 90% of the data in Figure 32 has PCI before treatment values ranging from 50 to 90, which is the general PCI range in which crack seal treatment is expected to be applied.

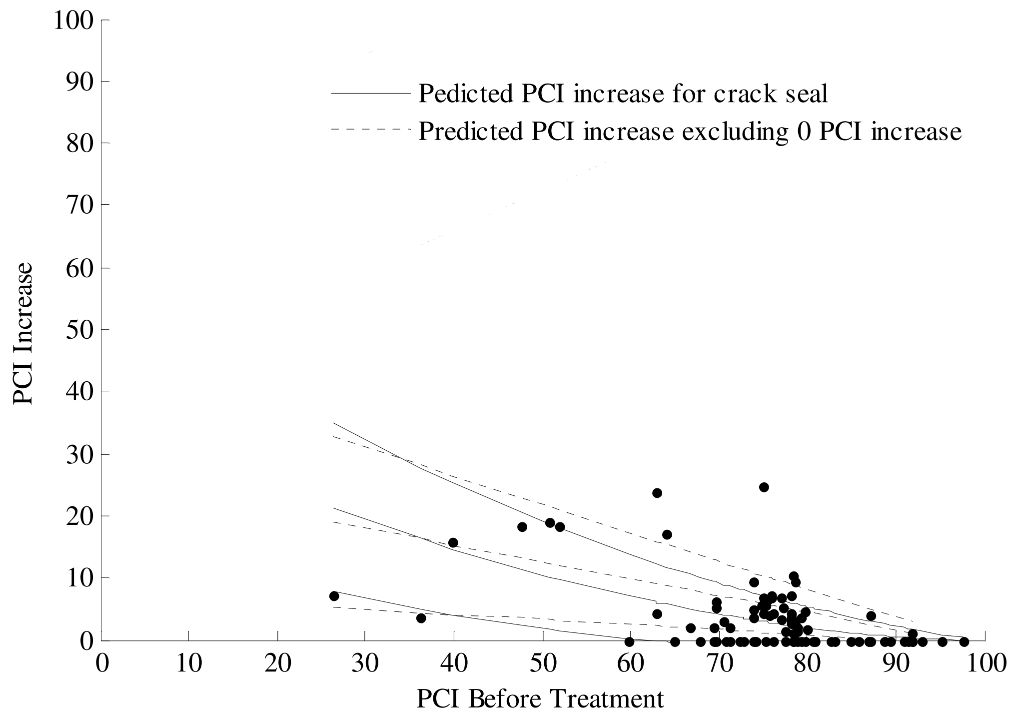

Figure 34: Mean and prediction interval for crack seal residential family with and without data sets with PCI increase as 0

Due to insufficient data in the crack seal treatment family, the data set cannot be further divided into different functional class and surface type families. More data should be obtained to develop the equations for each family to determine the PCI trends due to crack seal treatments accurately. Hence, the equation developed in Figure 32 in general can be used in the PMS to show the PCI increase trends for arterial AC, arterial AC/AC, collector AC, collector AC/AC, residential AC and residential AC/AC families for crack seal treatment.

Table 23 gives the regression coefficients of all the equations recommended to be used in the MTC-PMS.

Table 23: Regression coefficients for PCI increase due to slurry seal, cape seal and crack seal maintenance treatments for AC and AC/AC surface types

Treatment	Functional Class - Surface Type	Constant	PCI	PCI^2	R^2
Slurry Seal	General	66.292	-1.064	4.023E-03	0.314
	Arterial AC	69.556	-0.727	-	0.517
	Arterial AC/AC	66.292	-1.064	4.023E-03	0.314
	Collector AC	59.351	-0.612	-	0.549
	Collector AC/AC	66.292	-1.064	4.023E-03	0.314
	Residential AC	35.935	-0.363	-	0.137
	Residential AC/AC	95.222	-1.891	9.592E-03	0.572
Cape Seal	General	63.485	-1.109	4.932E-03	0.429
	Arterial AC	No Data Available for this Classification			
	Arterial AC/AC	No Data Available for this Classification			
	Collector AC	47.943	-0.484	-	0.403
	Residential AC	70.611	-1.369	7.118E-03	0.416
	Residential AC/AC	46.655	-0.497	-	0.591
Crack Seal	General	37.688	-0.710	3.297E-03	0.288

2.5 Calculation of PCI Loss/Year after Treatment

To evaluate the change in PCI after treatment the PCI loss/year after treatment is calculated based on the observed PCI values from inspections after treatment and the time between treatments. The PCI loss/year is plotted with respect to the PCI value before treatment, and a curve is fitted through these data sets to obtain the equation to determine the PCI loss/year after an applied treatment. The PCI loss/year is also plotted with respect to the time lapse between the treatment and the first post treatment inspection and a curve is fitted through these data sets to obtain an equation to determine PCI loss/year after an applied treatment. Regression analysis is completed for different groups like slurry seal, cape seal and crack seal generally called families in PMS [11]. In the subsequent tables of statistics, s is the estimate of error standard deviation of the developed equation. It gives the variability of PCI loss/year at a particular value of PCI before treatment and number of years to the first post treatment inspection. Low values of “s” indicate that the observed values of predicted variable (PCI loss/year) fall close to the developed equation line, and large values of “s” indicate that the observed values may deviate considerably from the developed line. As compared to the variability of the data for PCI loss/year values which is spread between 0 to 30, the observed value of “s” is high for the equations to determine PCI loss/year values.

2.5.1 Slurry Seal

Figure 35 shows the data sets for PCI loss/year for slurry seal treatments with respect to PCI before treatment. The main observation that can be made from Figure 35 is that the average PCI loss/year after application of a slurry seal is about 3.72. Table 24 gives the regression coefficients and the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained *F*-

statistics (F_0 = 0.867) for the 1st order polynomial equation is not greater than $f_{0.1,1,219}$ = 2.74 [17]. Similarly, the obtained *F*-statistics (F_0 = 0.519) for the 2nd order polynomial equation is not greater than $f_{0.1,2,218}$ = 2.34 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. Furthermore, the absolute value of the obtained *t*-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained *t*-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI before treatment and the PCI loss/year for the data analyzed.

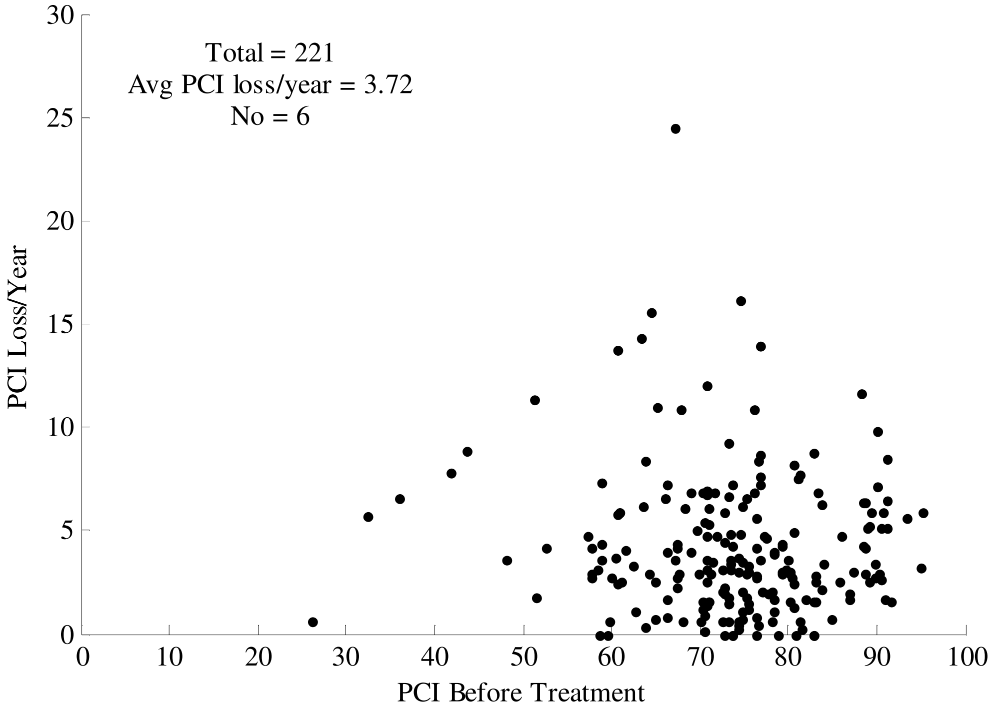

Figure 35: PCI loss/year for slurry seal treatments

Table 24: Coefficients of regression for PCI loss/year vs. PCI before treatment for slurry seal maintenance treatment

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	5.676	-0.020	-	3.500	0.867<2.74	4.054E-03
t-statistics	|3.551|>1.658	|-0.931|<1.658	-			
2nd order	7.712	-0.081	4.462E-04	3.507	0.519<2.34	4.870E-03
t-statistics	|1.501|<1.658	|-0.548|<1.658	|0.417|<1.658			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 36. The average time lapse between the treatment and the first post treatment inspection is about 2.9 years and it ranges from 0 to 6 years. Table 25 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained F-statistics ($F_0 = 0.329$) for the 1st order polynomial equation is not greater than $f_{0.1,1,219} = 2.74$ [17]. Similarly, the obtained F-statistics ($F_0 = 1.333$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,218} = 2.34$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute value of the obtained t-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the first and second order coefficients of the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for the data analyzed. Hence, an equation to determine the PCI loss/year trend for slurry seal family cannot be developed based on the available information.

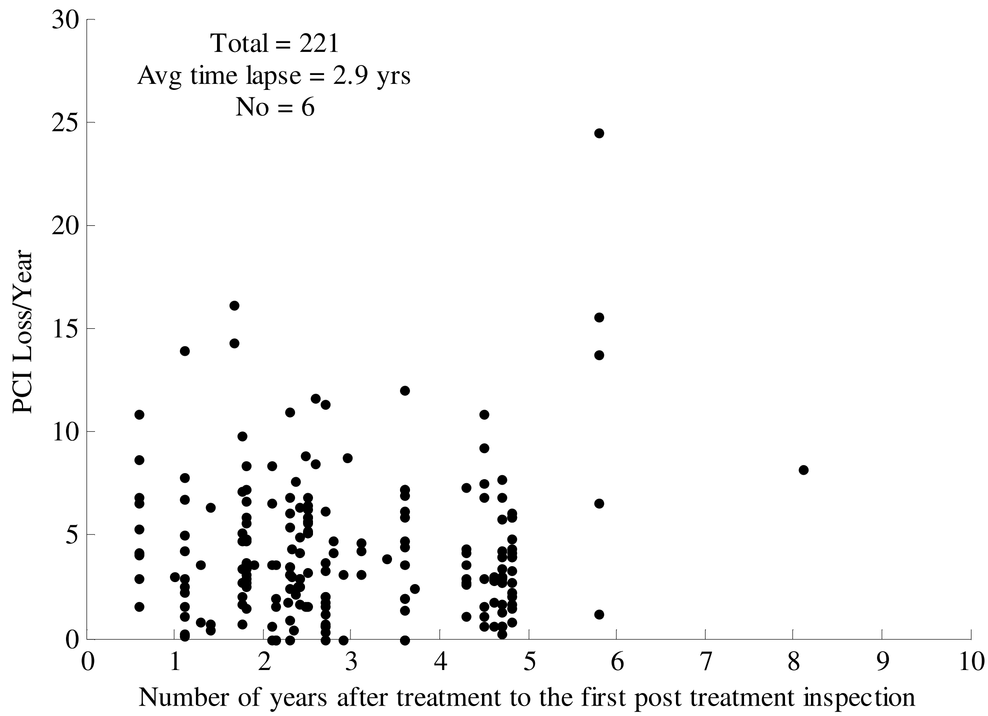

Figure 36: PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal treatments

Table 25: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal maintenance treatment

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	3.912	0.099	-	3.505	0.329<2.74	1.543E-03
t-statistics	|6.941|> 1.658	|0.574|< 1.658	-			
2nd order	6.759	-2.040	0.326	3.431	1.333<2.34	0.048
t-statistics	|6.475|> 1.658	|-1.469|< 1.658	|1.213|<1.658			

To see the effect of functional class and surface type, slurry seal family can be grouped in functional class and surface types like arterial AC, collector AC, collector AC/AC, residential AC and residential AC/AC. Table 26 gives the number of data sets used in the analysis for slurry seal treatment for all functional class surface type combination.

Table 26: Number of data sets for PCI loss/year for all functional class surface type combination for slurry seal

Functional Class - Surface Type	PCI Loss/Yr Data sets
Arterial AC	31
Arterial AC/AC	8
Collector AC	30
Collector AC/AC	0
Residential AC	127
Residential AC/AC	25
Total	221

Figure 37 shows the data sets for PCI loss/year for slurry seal arterial and surface type AC family with respect to PCI before treatment. The average PCI loss/year observed in this group is about 4.27. Table 27 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance (α = 0.1), the obtained F-statistics (F_0 = 0.0004) for the 1st order polynomial equation is not greater than $f_{0.1,1,29}$ = 2.89 [17]. Similarly, the obtained F-statistics (F_0 = 0.477) for the 2nd order polynomial equation is not greater than $f_{0.1,2,28}$ = 2.50 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. The absolute values of the obtained t-statistics for the coefficients of the 1st order polynomial equation are not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the first and the second order coefficients for the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the *t*-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI before treatment and the PCI loss/year for slurry seal arterial AC family for the data analyzed.

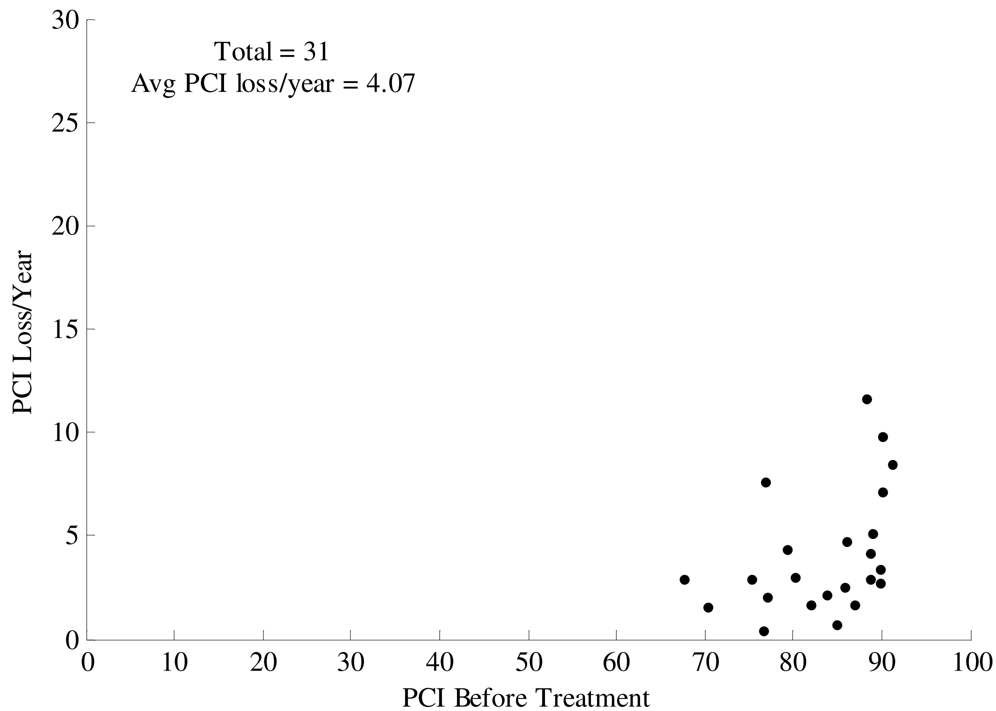

Figure 37: PCI loss/year equation for slurry seal treatments for functional class arterial and surface type AC

Table 27: Coefficients of regression for PCI loss/year vs. PCI before treatment for slurry seal maintenance treatment for functional class and surface type arterial AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	4.378	-0.001	-	3.130	4.334E-04<2.89	1.970E-05
t-statistics	|0.856|<1.701	|-0.021|<1.701	-			
2nd order	49.464	-1.337	9.439E-03	2.682	0.477<2.50	0.029
t-statistics	|3.152|>1.701	|-0.974|<1.701	|0.992|<1.701			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 38. The average time lapse between the treatment and the first post treatment inspection is about 2 years and it ranges from 1 to 3 years. Table 28 gives the regression coefficients and the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained *F*-statistics ($F_0 = 0.954$) for the 1st order polynomial equation is not greater than $f_{0.1,1,29} = 2.89$ [17]. Similarly, the obtained *F*-statistics ($F_0 = 1.506$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,28} = 2.5$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute values of the obtained *t*-statistics for the coefficients of the 1st order polynomial equation are not greater than the critical *t*-statistics. Similarly, the absolute values of the obtained *t*-statistics for the first and the second order coefficients for the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for slurry seal arterial AC family for the data analyzed. Hence, an equation to determine the PCI loss/year trend for slurry seal family arterial AC cannot be developed based on the available information.

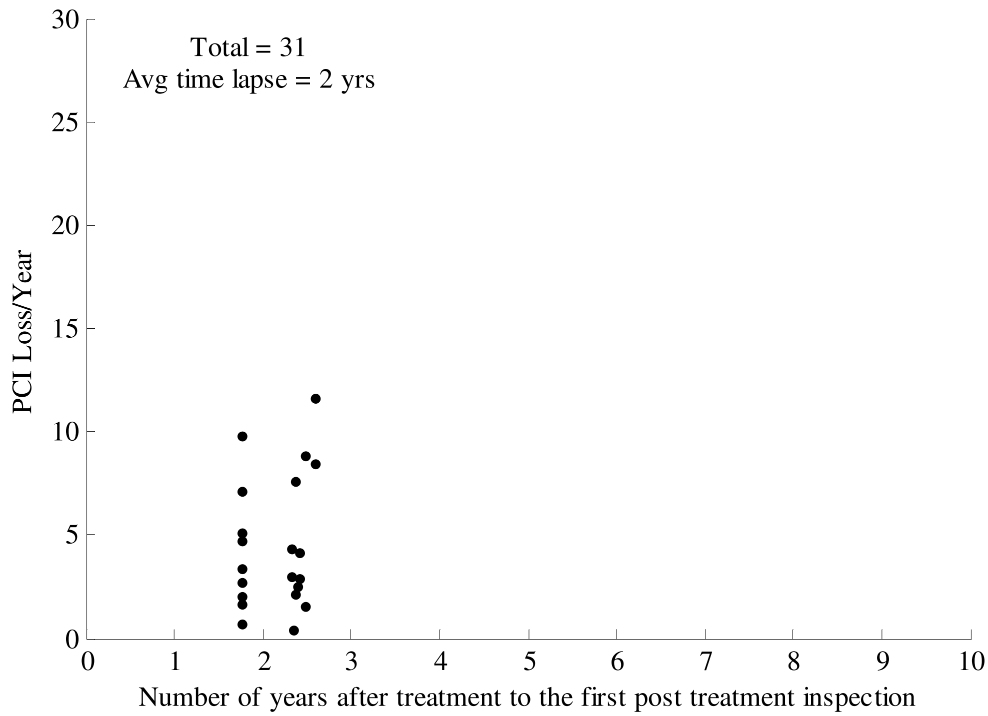

Figure 38: PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal arterial AC family

Table 28: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal maintenance treatment for functional class and surface type arterial AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	0.383	1.819	-	3.064	0.954<2.89	0.042
t-statistics	$\lvert 0.095\rvert<1.701$	$\lvert 0.977\rvert<1.701$	-			
2nd order	153.188	-147.543	35.554	2.619	1.506<2.5	0.058
t-statistics	$\lvert 3.018\rvert>1.701$	$\lvert -0.979\rvert<1.701$	$\lvert 1.018\rvert<1.701$			

Figure 39 shows the data sets for PCI loss/year for slurry seal collector and surface type AC family with respect to PCI before treatment. The average PCI loss/year observed for this family is about 3.35. Table 29 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained *F*-statistics ($F_0 = 1.070$) for the 1st order polynomial equation is not greater than $f_{0.1,1,28} = 2.89$ [17]. Similarly, the obtained *F*-statistics ($F_0 = 1.970$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,27} = 2.51$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. The absolute values of the obtained *t*-statistics for the coefficients of the 1st order polynomial equation are not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot to reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus, it can be concluded that there is no relation between the PCI before treatment and the PCI loss/year for slurry seal collector AC family for the data analyzed.

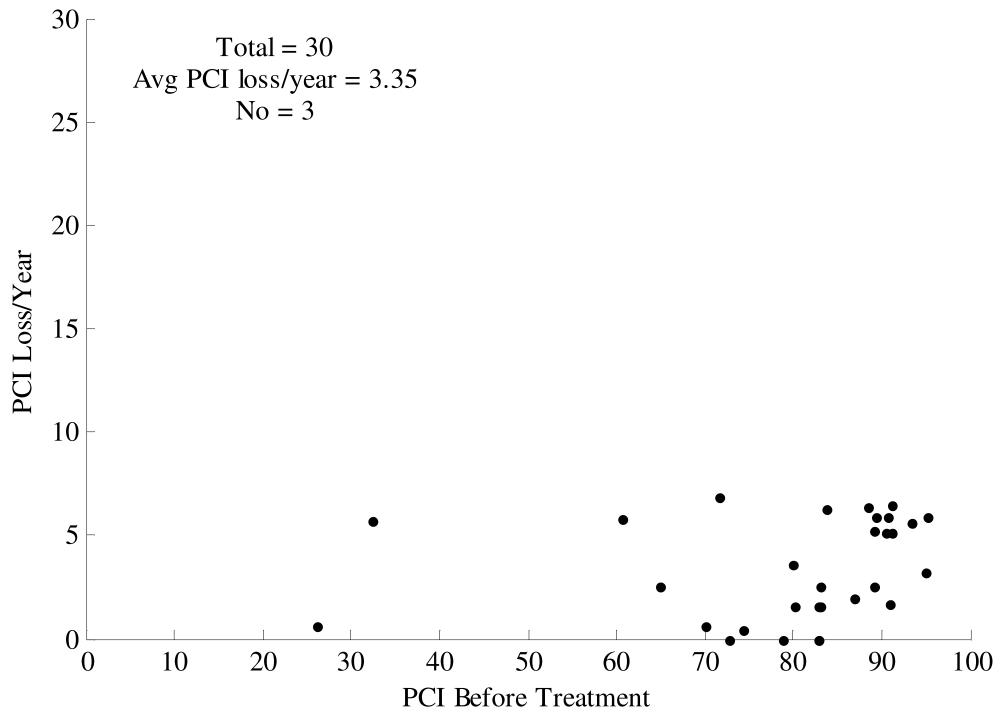

Figure 39: PCI loss/year equation for slurry seal treatments for functional class collector and surface type AC

Table 29: Coefficients of regression for PCI loss/year vs. PCI before treatment for slurry seal maintenance treatment for functional class and surface type collector AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	1.079	0.029	-	2.418	1.070<2.89	0.037
t-statistics	|0.481|<1.703	|1.034|<1.703	-			
2nd order	8.375	-0.236	2.091E-03	2.344	1.970<2.51	0.048
t-statistics	|1.701 |<1.703	|-1.473|<1.703	|1.674|<1.703			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 40. The average time lapse between the treatment and the first post treatment inspection is about 2.8 years and it ranges from 2 to 5 years. Table 30 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained F-statistics ($F_0 = 1.275$) for the 1st order polynomial equation is not greater than $f_{0.1,1,28} = 2.89$[17]. Similarly, the obtained F-statistics ($F_0 = 0.621$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,27} = 2.51$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute value of the obtained t-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the first and the second order coefficients of the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for slurry seal collector AC family based on the data analyzed. Hence, an equation to determine the PCI loss/year trend for slurry seal family collector AC cannot be developed based on the available information.

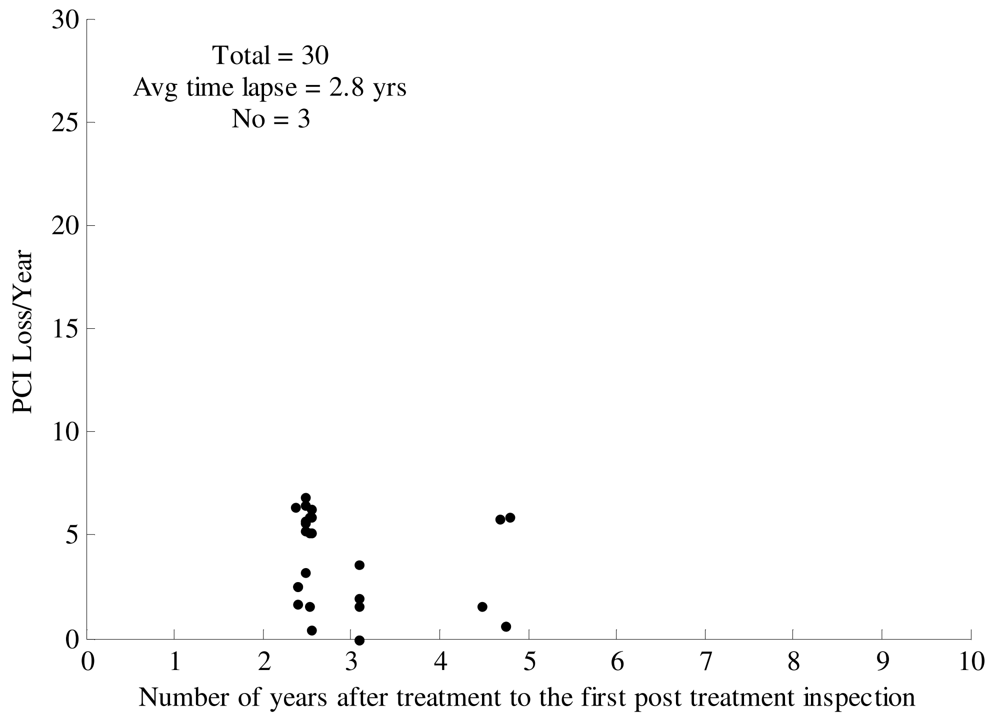

Figure 40: PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal collector AC family

Table 30: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal maintenance treatment for functional class and surface type collector AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	4.815	-0.506	-	2.370	1.275<2.89	0.042
t-statistics	|3.532|>1.703	|-1.129|<1.703	-			
2nd order	4.619	-0.359	-0.025	2.411	0.621<2.51	0.042
t-statistics	|1.955|>1.703	|-0.237|<1.703	|-0.102|<1.703			

Figure 41 shows the data sets for PCI loss/year for slurry seal residential and surface type AC family with respect to PCI before treatment. The average PCI loss/year observed for residential AC family for slurry seal treatments is about 3.87. Table 31 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomials equations are very low. For the desired level of significance (α = 0.1), the obtained F-statistics (F_0 = 0.668) for the 1st order polynomial equation is not greater than $f_{0.1,1,125}$ = 2.74 [17]. Similarly, the obtained F-statistics (F_0 = 0.753) for the 2nd order polynomial equation is not greater than $f_{0.1,2,124}$ = 2.34 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. The absolute value of the obtained t-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus, it can be concluded that there is no relation between PCI loss/year and PCI before treatment for slurry seal residential AC family based on the data analyzed.

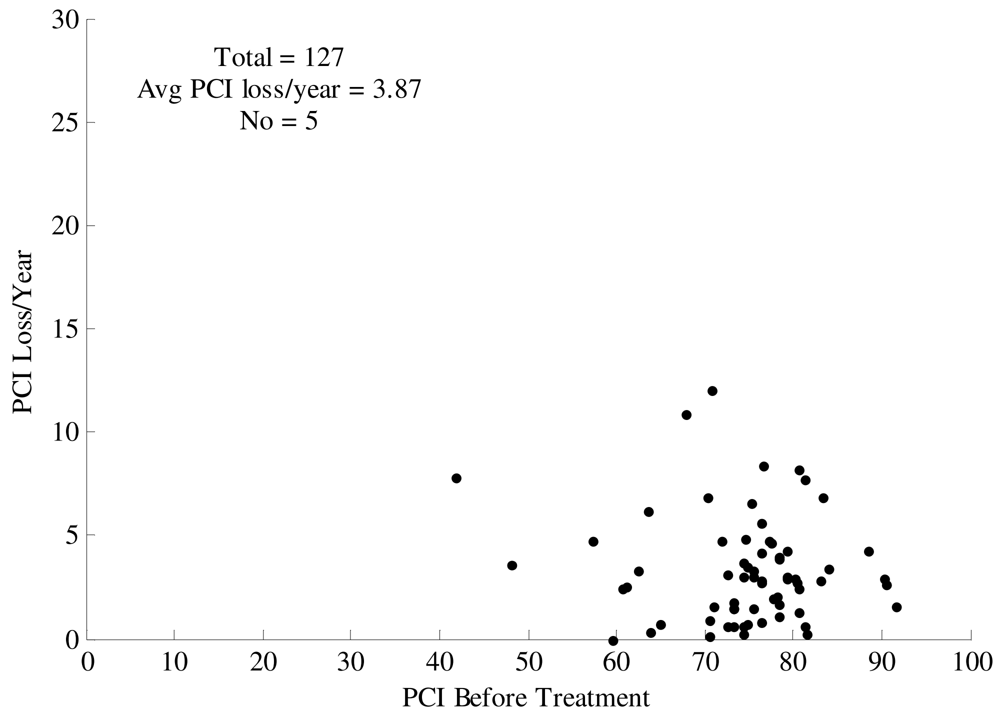

Figure 41: PCI loss/year equation for slurry seal treatments for functional class residential and surface type AC

Table 31: Coefficients of regression for PCI loss/year vs. PCI before treatment for slurry seal maintenance treatment for functional class and surface type residential AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	5.518	-0.030	-	2.569	0.668<2.74	0.010
t-statistics	|2.028|>1.658	|-0.817|<1.658	-			
2nd order	15.369	-0.320	2.095E-03	2.573	0.753<2.34	0.023
t-statistics	|1.386|<1.658	|-1.004|<1.658	|0.917|<1.658			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 42. The average time lapse between treatment and the first post treatment inspection is about 4 years and it ranges from 0 to 8 years. Table 32 gives the regression coefficients and the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the fitted equations. The

R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance (α = 0.1), the obtained *F*-statistics (F_0 = 0.804) for the 1st order polynomial equation is not greater than $f_{0.1,1,125}$ = 2.74 [17]. Similarly, the obtained *F*-statistics (F_0 = 0.851) for the 2nd order polynomial equation is not greater than $f_{0.1,2,124}$ = 2.34 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute value of the obtained *t*-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical *t*-statistics. Similarly, the absolute values of the obtained *t*-statistics for the first and the second order coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for slurry seal residential AC family based on the data analyzed. Hence, an equation to determine the PCI loss/year trend for slurry seal family residential AC cannot be developed based on the available information.

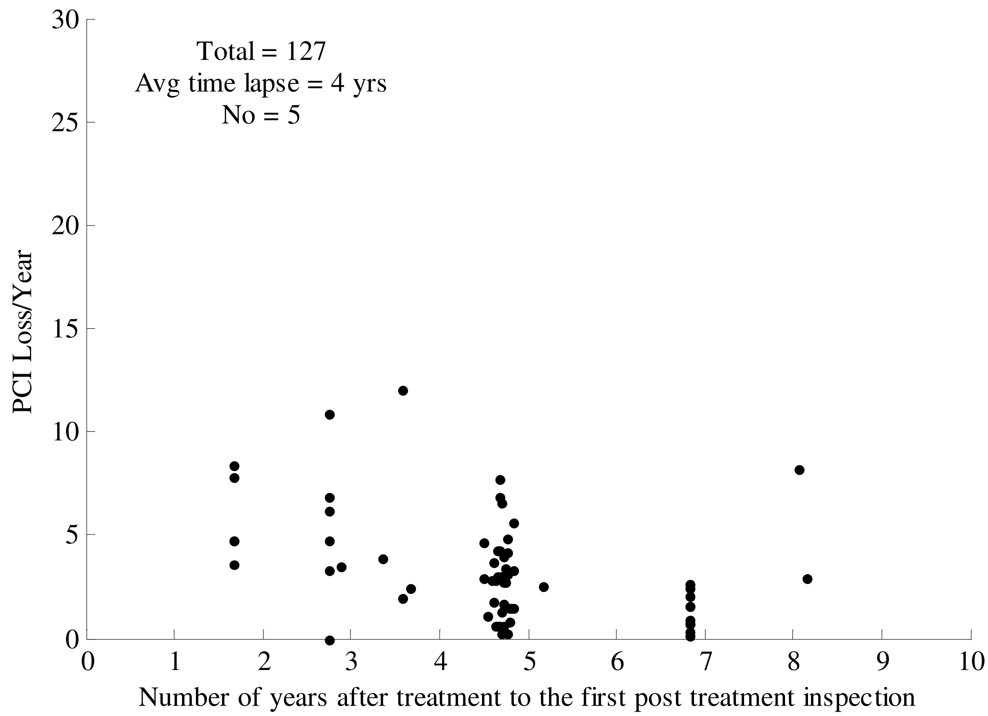

Figure 42: PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal residential AC family

Table 32: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal maintenance treatment for functional class and surface type residential AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	6.431	-0.675	-	2.373	0.804<2.74	0.015
t-statistics	|6.738|>1.658	|-1.436|<1.658	-			
2nd order	10.112	-2.429	0.188	2.312	0.851<2.34	0.021
t-statistics	|5.119|>1.658	|-1.498|<1.658	|1.112|<1.658			

The data available for functional class arterial and collector and surface type AC/AC are very few, therefore, the equation to determine the PCI loss/year trend for these families cannot be developed.

Figure 43 shows the data sets for PCI loss/year for slurry seal residential and surface type AC/AC family with respect to PCI before treatment. The average PCI loss/year is about 5.40. Table 33 gives the regression coefficients and the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance (α = 0.1), the obtained *F*-statistics (F_0 = 0.306) for the 1st order polynomial equation is not greater than $f_{0.1,1,23}$ = 2.94 [17]. Similarly, the obtained *F*-statistics (F_0 = 0.492) for the 2nd order polynomial equation is not greater than $f_{0.1,2,22}$ = 2.56 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that the relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial. The absolute values of the obtained *t*-statistics for the coefficients of the 1st order polynomial equation are not greater than the critical t-statistics. Similarly, the absolute values of the obtained *t*-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus, it can be concluded that there is no relation between PCI loss/year and PCI before treatment for slurry seal residential AC/AC family based on the data analyzed.

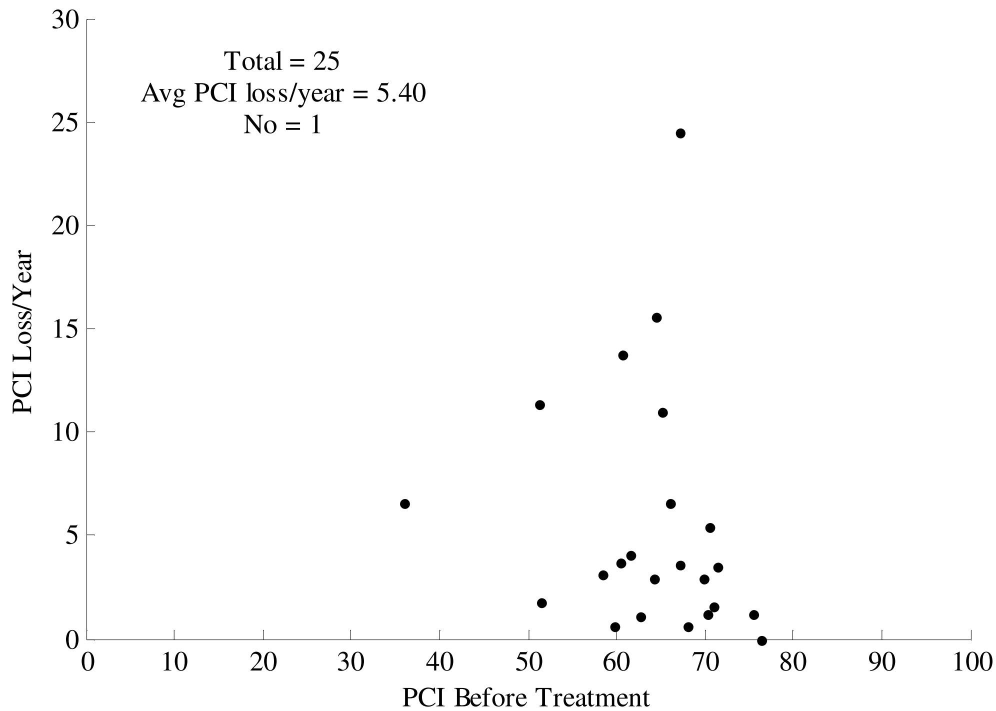

Figure 43: PCI loss/year equation for slurry seal treatments for functional class residential and surface type AC/AC

Table 33: Coefficients of regression for PCI loss/year vs. PCI before treatment for slurry seal maintenance treatment for functional class and surface type residential AC/AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	10.163	-0.075	-	5.892	0.306<2.94	0.013
t-statistics	|1.170|<1.717	|-0.553|<1.717	-			
2nd order	-17.381	0.904	-8.433E-03	5.933	0.492<2.56	0.043
t-statistics	|-0.504|<1.717	|0.757|<1.717	|-0.826|<1.717			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 44. The average time lapse between the treatment and the first post treatment inspection is about 3 years and it ranges from 0 to 7 years. Table 34 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The

R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance (α = 0.1), the obtained *F*-statistics (F_0 = 1.528) for the 1st order polynomial equation is not greater than $f_{0.1,1,23}$ = 2.94 [17]. Similarly, the obtained *F*-statistics (F_0 = 0.780) for the 2nd order polynomial equation is not greater than $f_{0.1,2,22}$ = 2.56 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute value of the obtained *t*-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained *t*-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for slurry seal residential AC/AC family based on the data analyzed. Hence, an equation to determine the PCI loss/year trend for slurry seal family residential AC/AC cannot be developed based on the available information.

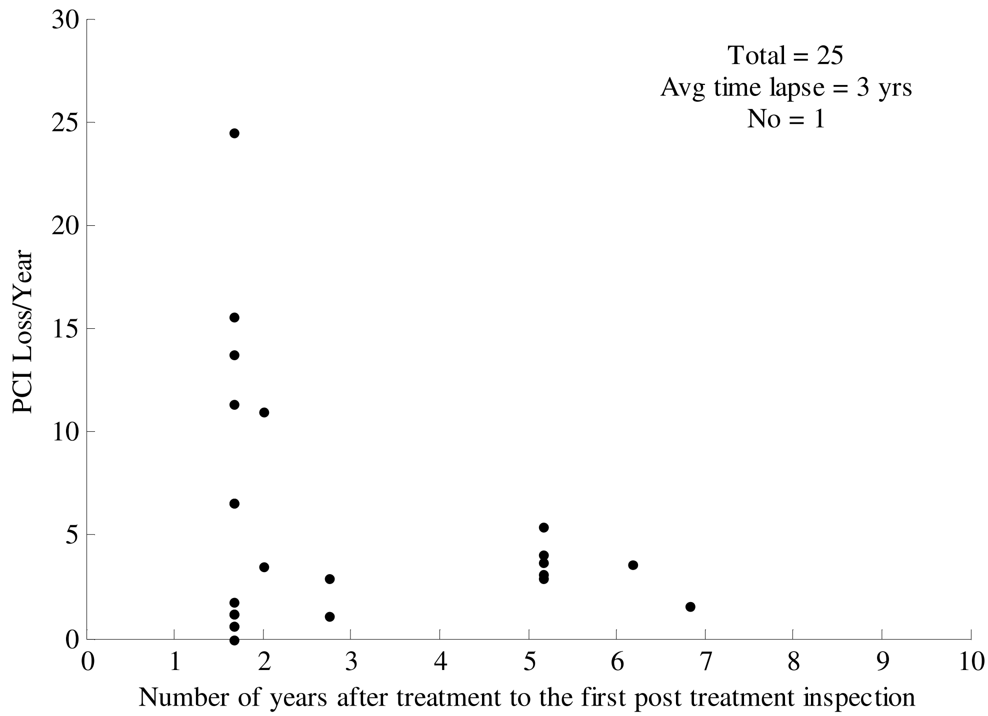

Figure 44: PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal residential AC/AC family

Table 34: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for slurry seal maintenance treatment for functional class and surface type residential AC/AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	7.759	-0.822	-	5.743	1.528<2.94	0.062
t-statistics	|3.484|>1.717	|-1.236|<1.717	-			
2nd order	9.912	-2.383	0.207	5.860	0.780<2.56	0.066
t-statistics	|1.332|<1.717	|-0.460|<1.717	|0.304|<1.717			

For all the functional class surface type combinations for slurry seal, no relation was found between the PCI loss/year and the PCI before treatment. Also, the PCI loss/year is independent of the number of years after treatment to the first post treatment inspection. Hence, the equations to determine the PCI loss/year trend after treatment slurry seal treatments cannot be developed based on the available data.

2.5.2 Cape Seal

Figure 45 shows the data sets for PCI loss/year for cape seal family with respect to PCI before treatment. The average PCI loss/per year after application of a cape seal is about 3.31. Table 35 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomials equations are very low. For the desired level of significance (α = 0.1), the obtained F-statistics ($F_0 = 0.545$) for the 1st order polynomial equation is not greater than $f_{0.1,1,126} = 2.74$ [17]. Similarly, the obtained F-statistics ($F_0 = 0.404$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,125} = 2.34$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. The absolute value of the obtained t-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between PCI loss/year and PCI before treatment for cape seal family based on the data analyzed.

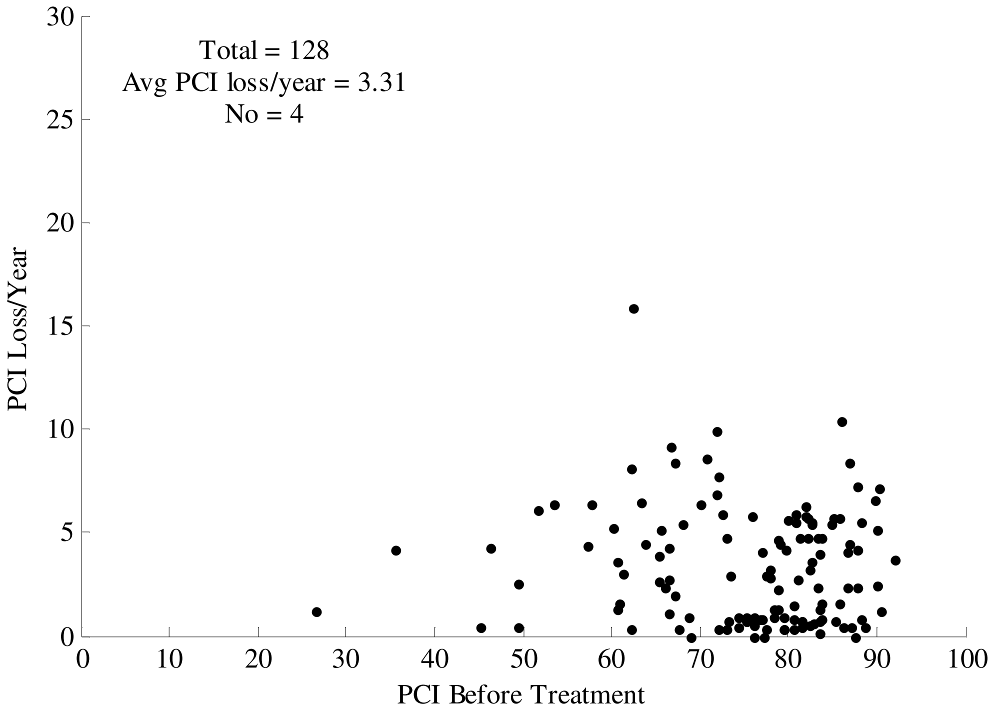

Figure 45: PCI loss/year for cape seal treatments

Table 35: Coefficients of regression for PCI loss/year vs. PCI before treatment for cape seal maintenance treatment

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	4.500	-0.016	-	2.804	0.545<2.74	4.304E-03
t-statistics	|2.766|>1.658	|-0.738|<1.658	-			
2nd order	1.901	0.065	-5.988E-04	2.813	0.404<2.34	6.418E-03
t-statistics	|0.359|<1.658	|0.411|<1.658	|-0.516|<1.658			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 46. The average time lapse between the treatment and the first post inspection after treatment is about 2.26 years and ranges from 0 to 5 years. Table 36 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained F-statistics ($F_0 = 0.697$) for the 1st order polynomial equation is not greater than $f_{0.1,1,126} = 2.74$ [17]. Similarly, the obtained F-statistics ($F_0 = 0.354$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,125} = 2.34$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute value of the obtained t-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for cape seal family based on the data analyzed. Hence, an equation to determine the PCI loss/year trend for cape seal family cannot be developed based on the available information.

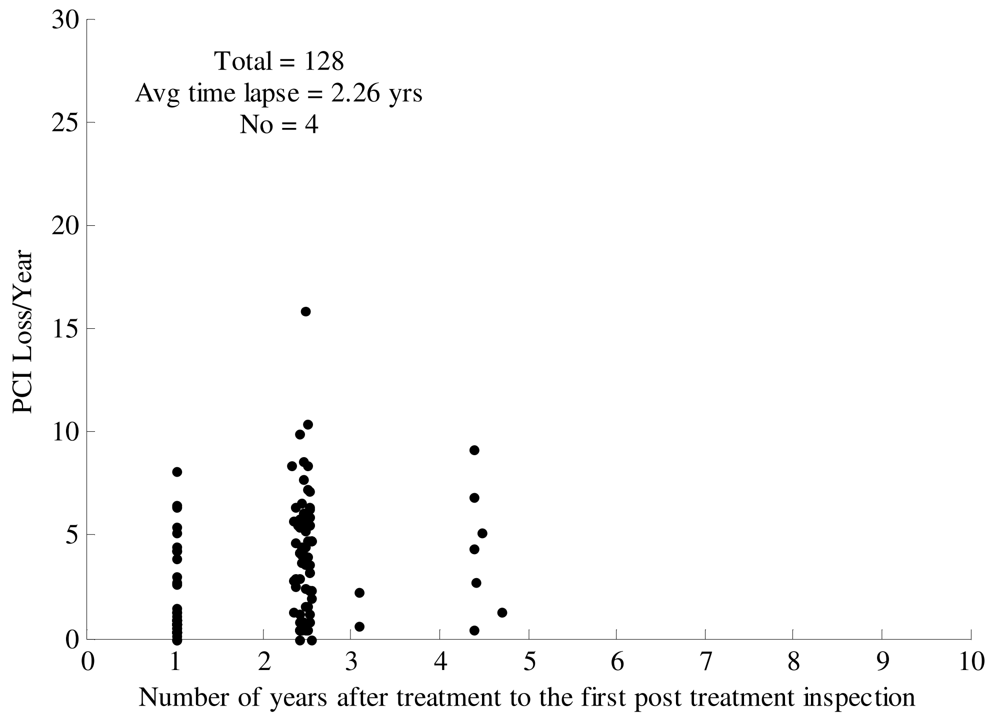

Figure 46: PCI loss/year vs. number of years after treatment to the first post treatment inspection for cape seal type of treatment

Table 36: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for cape seal maintenance treatment

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	1.171	1.020	-	2.660	0.697<2.74	0.014
t-statistics	|1.932|>1.658	|1.634|<1.658	-			
2nd order	-0.927	3.160	-0.462	2.614	0.354<2.34	0.042
t-statistics	|-0.861|<1.658	|1.325|<1.658	|-1.343|<1.658			

To see the effect of functional class and surface type, the data set is further grouped in functional class and surface types like collector AC and residential AC. Table 37 gives the number of data sets used in the analysis for cape seal treatment for all functional class and surface type combination.

Table 37: Number of data sets for PCI loss/year for all functional class surface type combination for cape seal

Functional Class - Surface Type	PCI Loss/Yr Data sets
Arterial AC	0
Arterial AC/AC	0
Collector AC	71
Collector AC/AC	14
Residential AC	43
Residential AC/AC	0
Total	128

PCI loss/year equation for cape seal arterial and surface type AC family cannot be developed, since no data is available. Also, enough data is not available to develop an equation for cape seal treatments for surface type AC/AC. Figure 47 shows the data sets for PCI loss/year for cape seal collector and surface type AC family with respect to PCI before treatment. The average PCI loss/year observed for collector AC family for cape seal treatments is about 3.77. Table 38 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomials equations are very low. For the desired level of significance (α = 0.1), the obtained F-statistics (F_0 = 0.117) for the 1st order polynomial equation is not greater than $f_{0.1,1,69}$ = 2.78 [17]. Similarly, the obtained F-statistics (F_0 = 0.622) for the 2nd order polynomial equation is not greater than $f_{0.1,2,68}$ = 2.38 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. The absolute value of the obtained t-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between PCI loss/year and PCI before treatment for the cape seal collector AC family based on the data analyzed.

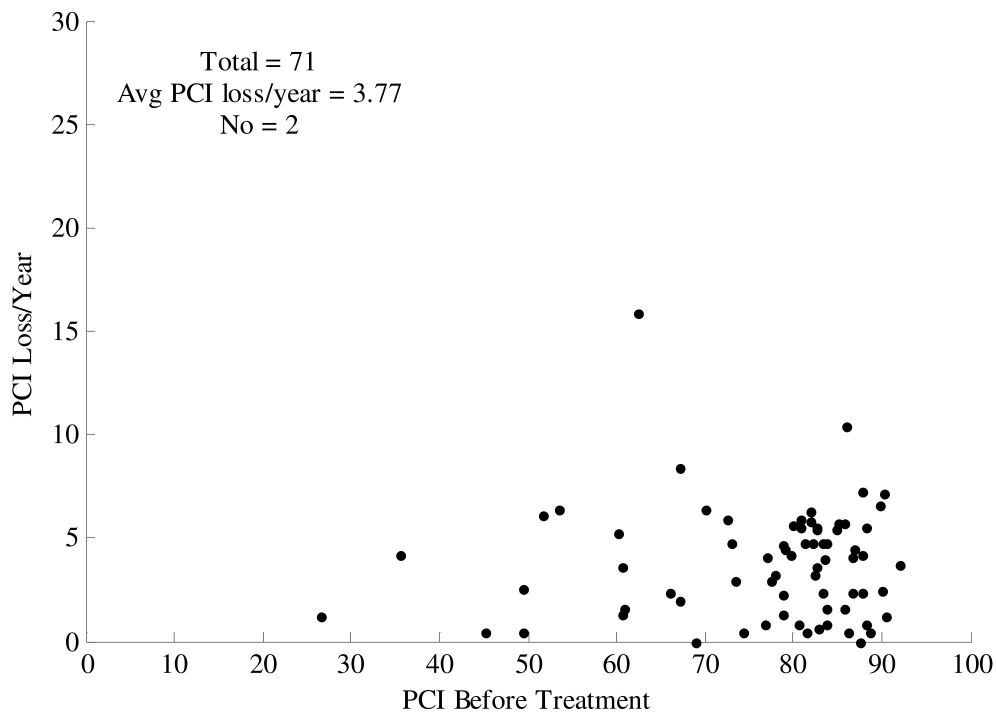

Figure 47: PCI loss/year equation for cape seal treatments for functional class collector and surface type AC

Table 38: Coefficients of regression for PCI loss/year vs. PCI before treatment for cape seal maintenance treatment for functional class and surface type collector AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	3.140	8.228E-03	-	2.729	0.117<2.78	1.692E-03
t-statistics	$\lvert 1.677 \rvert > 1.669$	$\lvert 0.342 \rvert < 1.669$	-			
2nd order	-2.568	0.195	-1.424E-03	2.726	0.622<2.38	1.798E-02
t-statistics	$\lvert -0.451 \rvert < 1.669$	$\lvert 1.098 \rvert < 1.669$	$\lvert -1.062 \rvert < 1.669$			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 48. The average time lapse between treatment and subsequent inspection is about 2.13 years and ranges from is 2 to 5 years. Table 39 gives the regression coefficients and the R^2, *F*-statistics and *t*-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance ($\alpha = 0.1$), the obtained *F*-statistics ($F_0 = 0.874$) for the 1st order polynomial equation is not greater than $f_{0.1,1,69} = 2.78$ [17]. Similarly, the obtained *F*-statistics ($F_0 = 0.433$) for the 2nd order polynomial equation is not greater than $f_{0.1,2,68} = 2.38$ [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute value of the obtained *t*-statistics for the first order coefficient of the 1st order polynomial equation is not greater than the critical *t*-statistics. Similarly, the absolute values of the obtained *t*-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for cape seal collector AC family based on the data analyzed. Hence, an equation to determine the PCI loss/year trend for cape seal collector AC family cannot be developed based on the available information.

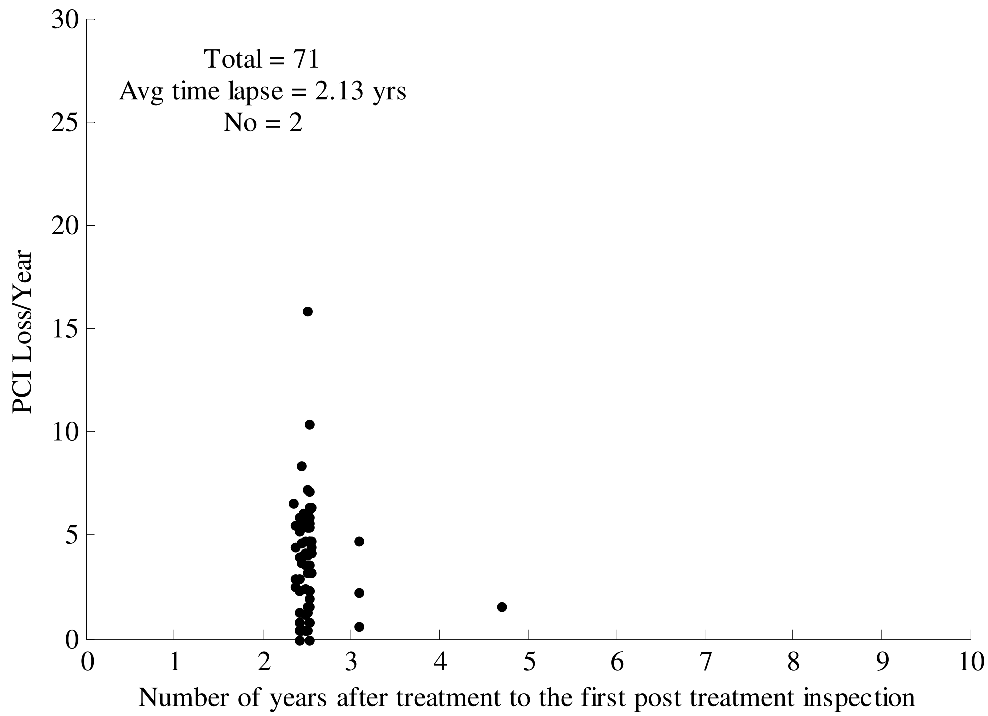

Figure 48: PCI loss/year vs. number of years after treatment to the first post treatment inspection for cape seal collector AC family

Table 39: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for cape seal maintenance treatment for functional class and surface type collector AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	6.387	-1.034	-	2.714	0.874<2.78	0.013
t-statistics	|2.267|>1.669	|-0.935|<1.669	-			
2nd order	5.330	-0.366	-0.098	2.734	0.433<2.38	0.013
t-statistics	|0.310|<1.669	|-0.034|<1.669	|-0.062|<1.669			

Figure 49 shows the data sets for PCI loss/year for cape seal residential surface type AC family with respect to PCI before treatment. The average PCI loss/year is about 1.82. Table 40 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. For the desired level of significance (α = 0.1), the obtained *F*-statistics (F_0 = 37.3) for the 1st order polynomial equation is greater than $f_{0.1,1,41}$= 2.84 [17]. Similarly, the obtained *F*-statistics (F_0 = 18.197) for the 2nd order polynomial equation is greater than $f_{0.1,2,40}$ = 2.44 [17]. Therefore, we can reject the null hypothesis (H_o) and conclude that a relationship exists between PCI loss/year and PCI before treatment for 1st and 2nd order polynomial equations. The absolute values of the obtained *t*-statistics for the coefficients of the 1st order polynomial are greater than the critical *t*-statistics. For the 2nd order polynomial, the absolute values of the obtained *t*-statistics for the coefficients are not greater than the critical *t*-statistics. Hence, we can reject the null hypothesis of the *t*-statistics for the 1st order polynomial equation; whereas, we cannot reject the null hypothesis of the *t*-statistics for the 2nd order polynomial equation. Also, the R^2 value observed for the 1st order polynomial equation is 0.4764 which indicates that it is a reasonable fit. Therefore, the 1st order polynomial equation can be used to determine PCI loss/year for cape seal residential AC family. However, for all the other functional class and surface type combinations for cape seal, it is observed that there is no relationship between PCI loss/year and PCI before treatment. Therefore, the equation developed to determine the PCI loss/year for cape seal residential AC family which is a subset of the cape seal family, data is of questionable reliability for determining the PCI loss/year trend for cape seal residential AC family. Hence, the equation developed cannot be recommended to predict the PCI loss/year trend for cape seal residential AC family. Further, Figure 50 shows the PCI loss/year data sets plotted with respect to number of years after treatment to the first post treatment inspection. Regression equations cannot be fitted to the data because all the datasets have same number of years after treatment to the first post treatment inspection. Hence, no statistical information is available to decide if there is a relationship between the PCI loss/year and number of years after treatment to the first post treatment inspection for cape seal residential AC family.

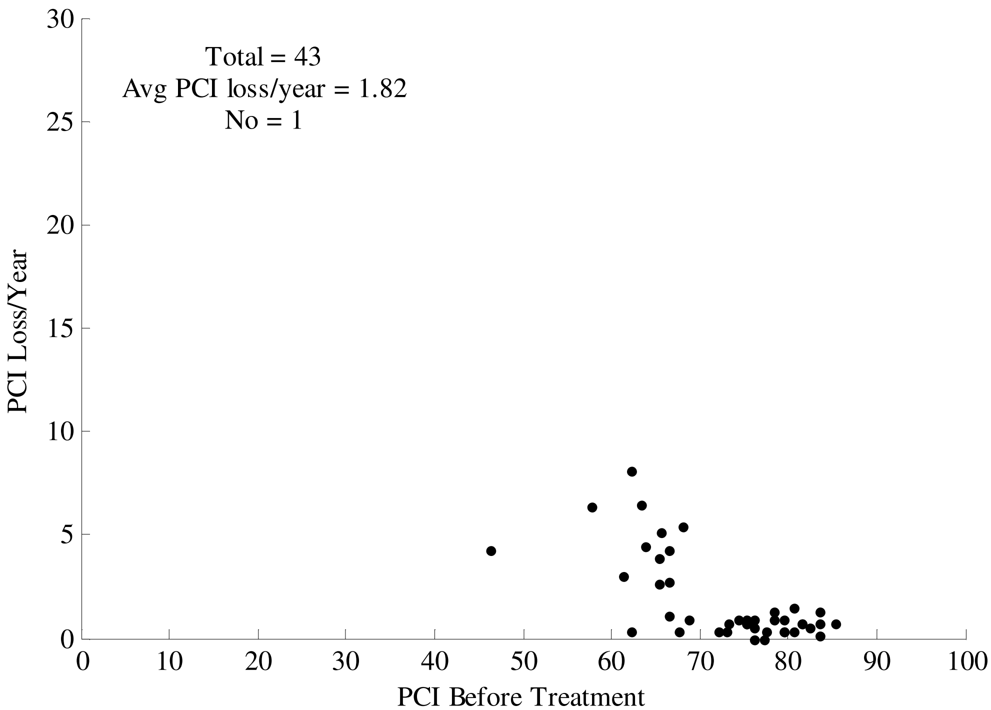

Figure 49: PCI loss/year equation for cape seal treatments for functional class residential and surface type AC

Table 40: Coefficients of regression for PCI loss/year vs. PCI before treatment for cape seal maintenance treatment for functional class and surface type residential AC

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	14.049	-0.168	-	1.498	37.300> 2.84	0.476
t-statistics	|6.970|>1.684	|-6.107|>1.684	-			
2nd order	14.531	-0.182	1.016E-04	1.517	18.197>2.44	0.476
t-statistics	|1.230|<1.684	|-0.533|<1.684	|0.041|<1.684			

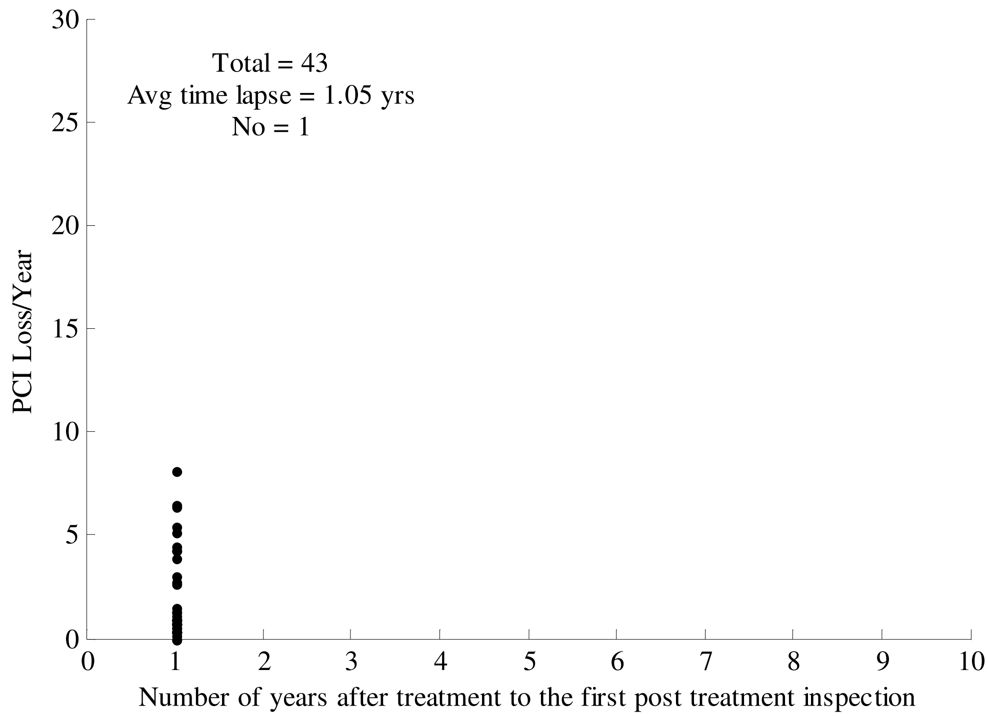

Figure 50: PCI loss/year vs. number of years after treatment to the first post treatment inspection for cape seal residential AC family

For all the functional class surface type combinations for cape seal, no significant relation was found between the PCI loss/year and the PCI before treatment, except for cape seal residential AC family. However, as discussed, the data used to develop the equation for cape seal residential AC family is of questionable reliability. Hence, the equation developed cannot be recommended to be used in the PMS. Also, the PCI loss/year is independent of the number of years after treatment to the first post treatment inspection. Hence, the equations to determine the PCI loss/year trend after cape seal treatments cannot be developed based on the available data.

2.5.3 Crack Seal

Figure 51 shows the data sets for PCI loss/year for cape seal family with respect to PCI before treatment. The average PCI loss/year after application of a cape seal is about 0.59. Table 41 gives the regression coefficients and the R^2, F-statistics and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance (α = 0.1), the obtained F-statistics (F_0 = 1.033) for the 1st order polynomial equation is not greater than $f_{0.1,1,10}$ = 3.29 [17]. Similarly, the obtained F-statistics (F_0 = 0.474) for the 2nd order polynomial equation is not greater than $f_{0.1,2,9}$ = 3.01 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and PCI before treatment for the 1st and 2nd order polynomial equations. . The absolute values of the obtained t-statistics for the coefficients of the 1st order polynomial equation are not greater than the critical t-statistics. Similarly, the absolute values of the obtained t-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical t-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between PCI loss/year and PCI before treatment for crack seal family for the data analyzed.

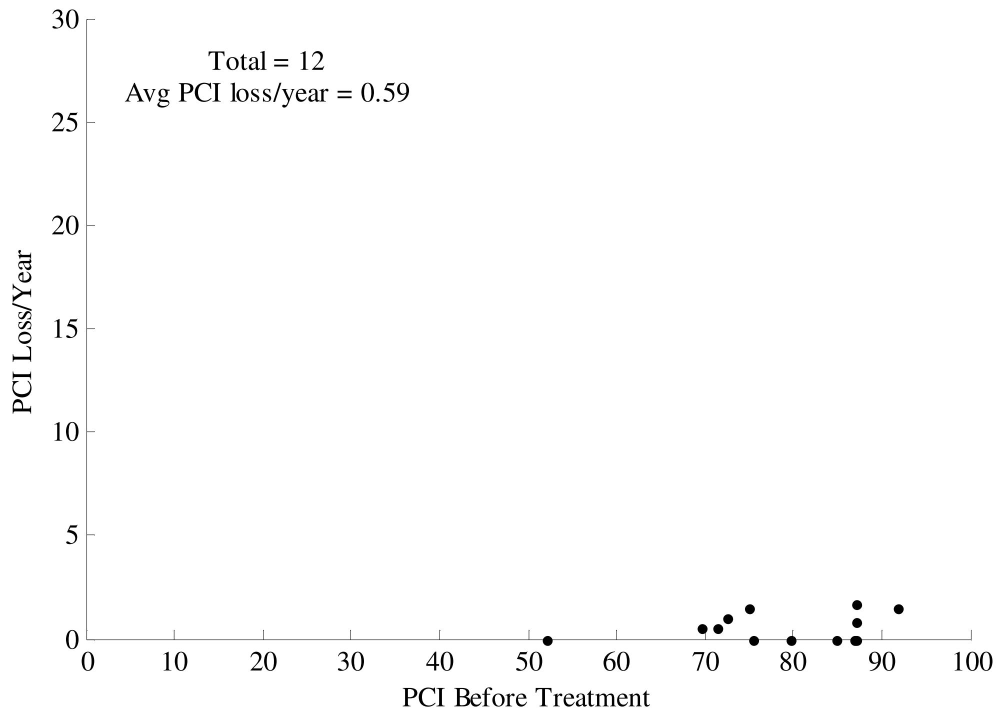

Figure 51: PCI loss/year for crack seal treatments

Table 41: Coefficients of regression for PCI loss/year vs. PCI before treatment for crack seal maintenance treatment

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	-0.730	0.017	-	0.628	1.033<3.29	0.079
t-statistics	|-0.557|<1.833	|1.016|<1.833	-			
2nd order	-0.566	0.012	3.119E-05	0.656	0.474<3.01	0.079
t-statistics	|-0.080|<1.833	|0.063|<1.833	|0.024|<1.833			

The PCI loss/year data sets were also plotted with respect to number of years after treatment to the first post treatment inspection as seen in Figure 52. The average time lapse between treatment and subsequent inspection is about 2 years and ranges from is 0 to 3 years. Table 42 gives the regression coefficients and the R^2, F-statistics, and t-statistics values used for statistical evaluation of the fitted equations. The R^2 values for the 1st and 2nd order polynomial equations are very low. For the desired level of significance (α = 0.1), the obtained *F*-statistics (F_0 = 0.896) for the 1st order polynomial equation is not greater than $f_{0.1,1,10}$ = 3.29 [17]. Similarly, the obtained *F*-statistics (F_0 = 0.440) for the 2nd order polynomial equation is not greater than $f_{0.2,1,9}$ = 3.01 [17]. Therefore, we cannot reject the null hypothesis (H_o) and conclude that a relationship does not exist between PCI loss/year and number of years to the first post treatment inspection for the 1st and 2nd order polynomial equations. The absolute values of the obtained *t*-statistics for the coefficients of the 1st order polynomial equation are not greater than the critical *t*-statistics. Similarly, the absolute values of the obtained *t*-statistics for the coefficients of the 2nd order polynomial equation are not greater than the critical *t*-statistics. Hence, we cannot reject the null hypothesis of the t-statistics for the 1st and 2nd order polynomial equations. Thus it can be concluded that there is no relation between the PCI loss/year and number of years after treatment to the first post treatment inspection for crack seal family for the analyzed data. Hence, an equation to determine the PCI loss/year trend for crack seal family cannot be developed based on the available information.

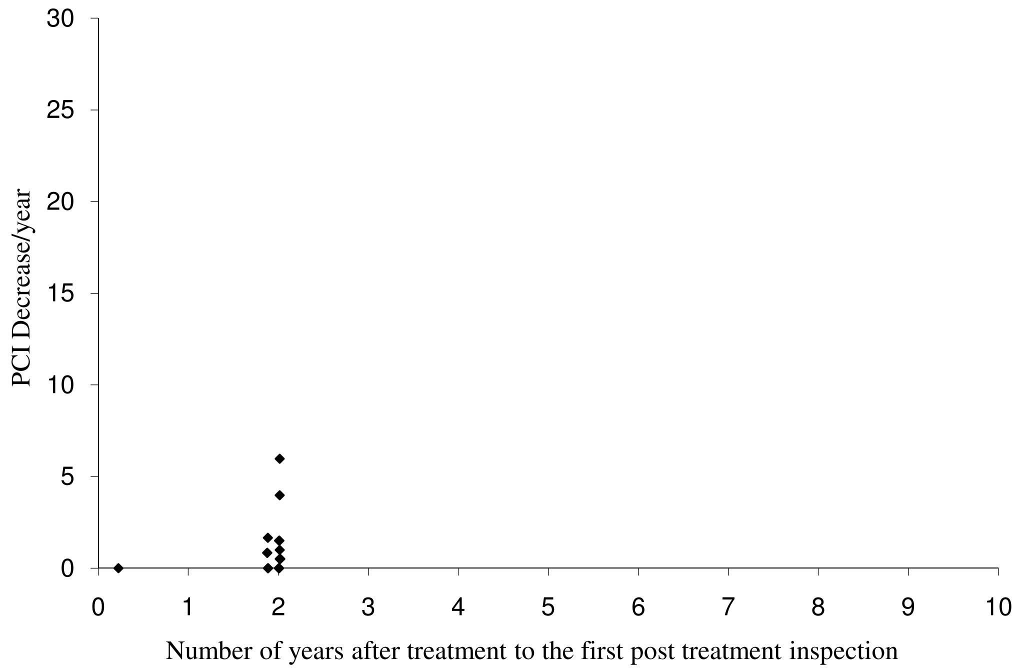

Figure 52: PCI loss/year vs. number of years after treatment to the first post treatment inspection for crack seal treatments

Table 42: Coefficients of regression for PCI loss/year vs. number of years after treatment to the first post treatment inspection for crack seal maintenance treatment

Type of Polynomial	Intercept	x	x^2	s	F-statistics	R^2
1st order	-0.059	0.354		0.632	0.896<3.29	0.070
t-statistics	|-0.084|<1.833	|0.947|<1.833				
2nd order	-0.259	1.242	-0.400	0.658	0.440<3.01	0.074
t-statistics	|-0.229|<1.833	|0.325|<1.833	|-0.133|<1.833			

CHAPTER III

SUMMARY AND CONCLUSIONS

A pavement management system (PMS) helps to manage a pavement network and provides information for supporting an overall asset management system. Prediction models are essential analysis tools in a PMS and are used to predict the performance of the pavement with and without treatments. Many researchers have developed performance prediction models to predict the pavement condition in future; however, little research has been completed to determine the impact of maintenance treatments on the condition of pavement sections after treatments.

This research is conducted to develop the equations to predict the increase in pavement condition due to maintenance treatments and the rate of loss of pavement condition after treatment. These equations in addition to the performance curves can be used in a PMS to determine the effectiveness of maintenance and rehabilitation treatments. Local agency pavement network databases are used to develop the prediction equations. Prediction equations are developed by using the Pavement Condition Index (PCI) which is based on the pavement distress data observed on the pavement surface.

The data from the MTC-PMS software developed by the Metropolitan Transportation Commission (MTC) located in Oakland, California is used to develop the equations; the equations developed can be used to predict the condition of sections similar to the ones on which the equations were developed since are they based on empirical methods. Hence, the conclusions and findings from this study are applicable only to MTC pavement management system for San Francisco, Bay area pavement networks. However, the methodology could be applied to other areas if appropriate data for those areas are available. The following is concluded from the study:

a) For all the functional class and surface type combinations for slurry seal, cape seal and crack seal it is observed that as the value for PCI before treatment for a particular section increases, the predicted PCI increase value due to treatment for that section decreases.

b) When the PCI before treatment is 70, the average PCI increase for slurry seal type of treatment is observed to be about 13, for cape seal type of treatment is about 10 and for crack seal is about 5. The PCI increase after treatment is greater for slurry seal and cape seal type of treatments as compared to crack seal treatments at this treatment level.

c) Figure 17 and Figure 31 give the summary of the equations recommended for the use in the MTC-PMS to show the PCI increase trends for slurry seal and cape seal respectively. Since, the equations have lower R^2 values, they should be used to show the trend in PCI increase values rather than predict the PCI increase values accurately. Table 23 gives the regression coefficients of all the equations recommended to be used in the MTC-PMS.

d) The average PCI loss/year for slurry seal treatments is about 3.72 and about 3.31 for cape seal treatments.

e) The R^2 and F-statistics of all the fitted equations for PCI loss/year are generally very low which indicates that there is large variability in the data.

f) No relation between the PCI loss/year value and the PCI before treatment was recommended. Also, it is observed that there is no relation between the PCI loss/year and the average time lapse between treatment and subsequent inspection. Therefore, more information would be needed to develop the equations to determine PCI loss/year trends for all treatments as a function of PCI at the time of treatment if such relationship exists.

g) Since enough data is not available for all the functional class surface type combinations the equations developed in this research project to show the PCI increase trends after treatment, should be considered as a beginning set of equations. As MTC collects more data the equations should be upgraded to show the PCI increase with treatment trends more accurately.

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APPENDIX A

Table A - 1: Default Values for Alpha, Beta, and Rho

Functional Classification	Surface Type	Alpha	Beta	Rho
Arterial	AC	88	0.58	109
	AC/AC	60	0.83	50
	AC/PCC	60	0.83	50
	PCC	215	0.45	90
	ST	27	1.95	43
Collector	AC	79	0.48	106
	AC/AC	69	0.77	59
	AC/PCC	69	0.77	59
	PCC	215	0.45	90
	ST	27	1.95	43
Residential	AC	110	0.61	97
	AC/AC	136	0.58	112
	AC/PCC	136	0.58	112
	PCC	230	0.50	80
	ST	27	1.95	43
Other	AC	110	0.61	97
	AC/AC	136	0.58	112
	AC/PCC	136	0.58	112
	PCC	230	0.50	80
	ST	27	1.95	43

Table A - 2: Regression Coefficients for PCI Increase Due Maintenance Treatments for All Asphaltic Surface Types (AC, AC/AC, AC/PCC, & ST)

Treatment	Constant	PCI	PCI^2	PCI^3	PCI^4	PCI^5
Crack Seal	0.430	5.56E-2	3.23E-2	-4.31E-5	-1.05E-7	2.01E-9
Crack Seal & Surface Seal	-2.34	+0.935	-2.66E-2	3.31E-4	-1.57E-6	
Crack Seal, Patch & Surface Seal	42.19	-0.383	-0.0168	3.56E-4	-1.92E-6	

Table A - 3: Regression Coefficients for PCI Increase Due Maintenance Treatments for All Portland Cement Concrete Surface Types (PCC)

Treatment	Constant	PCI	PCI^2	PCI^3	PCI^4
Crack Sealing & Localized	+1.480	+2.292	-0.0883	+0.00114	-0.00000486

VITA

Maithilee Mukund Deshmukh received her Bachelor of Engineering degree in civil engineering from Sardar Patel College of Engineering, Mumbai, India in 2004. Upon completion, she worked for 2 years for Reliance Energy Limited, India wherein she was involved in the construction of substations. She entered the Infrastructure Engineering and Management program at Texas A&M University in January 2007 and received her Master of Science degree in civil engineering in May 2009. Her research interests include project infrastructure management, project finance, and optimization.

Ms. Maithilee may be reached at CE/TTI 705, 3136 TAMU, College Station, TX 77843, USA. Her email is maithileed@gmail.com.